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# Contamination Control in Healthcare Systems

Adam Scott Coen
*Worcester Polytechnic Institute*

Christopher Robert Gorgone
*Worcester Polytechnic Institute*

Michael G. Chadwick
*Worcester Polytechnic Institute*

Peter Nowak
*Worcester Polytechnic Institute*

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# CONTAMINATION CONTROL IN HEALTHCARE SYSTEM

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by


Michael Chadwick
Biology

Adam Coen
Civil Engineering

Christopher Gorgone
Biomedical Engineering

Peter Nowak
Civil Engineering


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Approved by:

Professor Mustapha S. Fofana, PhD, Advisor

Director of MIRAD Laboratory, Mechanical Engineering Department

## ABSTRACT

Contamination has proven itself to be a major threat to the health and safety of both patients and professionals in the healthcare system. Many types of disease causing pathogens have developed the ability to survive outside of an organic host, and proliferate throughout a patient-centric setting. Pathogenic diseases can come from sources like blood, air, and human waste, through direct and indirect contact. Hospitals and ambulances have developed and implemented standards to control harmful contaminants, yet millions of people contract healthcare associated infections every year. The result of these infections generates multi-billions dollar costs for hospitals each year. The purpose of this project is to research and analyze current healthcare standards, common sources of contamination, and methods of cleaning and disease prevention in order to find and fix any shortcomings or faults that increase the risk of infection. A myriad of ideas have been developed throughout the healthcare community over the last several years, but few have seen widespread implementation or success.

The results from this research could prove to be vital in reducing the risk of nosocomial infections, and ultimately death, in healthcare settings. If safe and cost effective preventative measures can be implemented on a wide scale throughout the healthcare system, the suffering of many will be reduced, and the economical strain placed on hospitals and clinics can be minimized. This research is not limited for suggestions within the United States alone. Many regions in the world do not have as refined cleanliness standards as the United States and countries in Europe do. This research also provides a background for future research to advance in preventing nosocomial infections and refining healthcare cleaning standards.

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## ACKNOWLEDGEMENTS

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# CHAPTER 1. EMS AND LIFESAVING PRACTICES

## 1. Introduction

Emergency Medical Service (EMS) has provided great care in the United States for almost 100 years. Currently, the EMS system follows set standards for their pre-hospital and traditional hospital care. These standards include proper ambulance design and equipment, proper ambulance decontamination and emergency protocol and proper health guidance while working in a hospital. Despite these standards, many threats to patients and EMS personnel still exist. For example, contamination presents a serious threat within the healthcare setting. Every year over 1 million people in the United States contract healthcare associated infections (HAIs). As a result, approximately 99,000 die. These infections can generate annual costs of over $30 billion in U.S. hospitals. Hospitals and ambulances are exposed to various forms of microbial life, like bacteria, viruses and fungi.

The purpose of this project is to research and investigate current healthcare standards, common sources of contaminants, and methods of cleaning and preventing contaminants. To gain better insight we have conducted research and collaborated with local Massachusetts EMS personnel to receive their thoughts and opinions about the impact of contaminants on patient care. The sheer volume of people and amount of activity in a hospital allows for contaminants to spread easily. Controlling and cleaning contaminants is a large issue in a hospital setting, but is just as severe in the enclosed environment of an ambulance. With personnel constantly on call, there may not be time between calls to properly clean and decontaminate the workplace, posing more risks for them and the next patients to be tended to. Considering these constraints, we have drafted goals for our project: (1) understand current healthcare standards, (2) identify contaminant threats within the healthcare system and (3) introduce improved methods of

sanitation and preventing contamination. The remaining part of this project is categorized as follows:

Chapter 2 presents background on EMS and healthcare standards. The different pathogenic risks, contaminant threats, and information of prevalent pathogenic diseases are also highlighted. This includes information on the various types, sources and modes of transmission of contaminants, and how each imposes risk of infecting ambulance occupants. This chapter will also include documented cases of disease exposure and cleaning procedures of contaminants in hospitals and ambulances. Chapter 3 contains our recommendations of contamination control technology. A detailed background and analysis will be provided for each device, as well as their impact in the healthcare industry. Each device serves a different purpose for the eradication of contaminants. Some have already been instilled in emergency triage units, while others are relatively new technologies that could help the healthcare system in the future. While no changes to protocol have been made, suggestions for technologies to be used for all ambulance providers have been derived. Lastly, Chapter 4 will conclude the project and summarize our derived results and their impact. References for the project have been provided, as well as appendices to review further information for results found during the research. The group presentation and authorship can be found at the end of the document.

# CHAPTER 2. EMS AND PATIENT QUALITY CARE

## 2. Introduction

The Anglo-American model of patient care is centered on the practice of performing life saving techniques to keep patients alive en route to a hospital or medical care facility. The US Bureau of Labor Statistics has listed criteria of care duties in order of need (US Bureau of Labor Statistics, [1]). The current organization of the EMS system was derived from these requirements. Standards such as the KKK, NFPA, and AMD, provide a comprehensive guide for EMS providers. It is imperative, especially in a modern medical environment with consistently changing conditions, to enforce effective and efficient sanitation methods to increase the safety of both emergency medical technicians and their patients. As we discover pathogens that are perpetually strengthening their defenses against conventional sterilization techniques (Carelton [2]), we must adapt our standards and techniques to keep EMS personnel and patients safe and healthy.

The intent of this project is to evaluate standards and produce solutions for contaminant prevention and cleaning. The many different complex surfaces and materials within an ambulance or hospital provide opportune breeding ground for transmissible diseases. Pathogens left untreated on stretchers, medical equipment, or protective gear not only pose a threat to EMS personnel, but also patients, whose immune systems may be compromised dude to disease. To reduce the risk of infection it is essential to provide a sanitary environment. To understand the importance of sterility within the healthcare system, one must first understand the working environment, and the job requirements of each emergency medical technician.

## 2.1 Levels of Care

In order to understand cleaning standards and contamination awareness, EMS professionals must complete multiple levels of training to earn certifications for treating patients. EMTs can complete up to four certifications, starting with training in basic life support. Basic life support procedures are generally practiced in a pre-hospital setting, sometimes without equipment. An individual will become certified as a first responder once they have completed 40-60 hours of basic life support training. First responders are trained in cardiopulmonary resuscitation (CPR), automated external defibrillator usage, spinal and bone fracture immobilization, oxygen treatment, advanced first aid, and emergency childbirth procedures. Once the individual has completed 150 hours of training, they are certified as Basic Emergency Medical Technicians (otherwise referred to as EMT-Bs). The additional training EMT-Bs must acquire teaches them how to treat non-visualized airways, and administer nitroglycerin (to prevent angina pectoris) and aspirin to the patient. EMTs can acquire advanced certification with just 100 more hours of training. EMT-As are certified in cardiac monitoring and employing intravenous access techniques (for infusing medications into the patients bloodstream) (*Emergency Response* [3]).

EMTs have the opportunity to complete more training to become certified as paramedics. Paramedics receive the most training and are qualified to perform more life saving techniques than any other EMT classification. Paramedics undergo approximately 1500 hours of training, typically covering the span of 18 to 24 months to complete. Paramedics are highly trained in all basic life support skills, as well as manual defibrillation operation, transcutaneous cardiac pacing and advanced airway management. Paramedics are the most exposed to medical equipment, like hypodermic needles, due to their extensive training. In order to prevent cross contamination,

paramedics must know all procedures for cleaning contaminated spills and surfaces. Additionally, paramedics are trained to perform continuous positive airway pressure (CPAP), rapid sequence induction, and pleural decompression.

## 2.2 Contaminants

Contaminants in a healthcare setting pose a serious threat to the treatment of patients as well as the health of medical professionals. These contaminants can come in a variety of forms including disease-causing pathogens, bodily fluids and air pollutants. Each of these can cause unique problems within the healthcare setting. There are several types of disease-causing pathogens, but the main types include bacteria, viruses, and fungi. Bacteria are single-celled prokaryotic organisms. The human body provides an ideal environment for many bacteria to strive and reproduce. While the majority of bacteria that inhabit the human body are harmless or even beneficial, several species of bacteria can cause harmful and potentially fatal diseases. The most notable bacterial infections in healthcare settings include methicillin resistant staphylococcus aureus (MRSA), tuberculosis and some forms of pneumonia.

Viruses are a particularly aggressive type of pathogen. They consist of a strand of genetic material in the form of DNA or RNA, a protein coat for protection, and occasionally a layer of lipids outside the protein coat. Because viruses lack organelles responsible for DNA/RNA synthesis and protein development, they require a host cell to reproduce. To accomplish this, the virus attaches to the host cell and injects its genome through either direct fusion with the cell or through receptor-mediated endocytosis (a process in which the virus attaches to a receptor on the cell membrane and is then engulfed by the cell in the form of a vesicle). Common viral infections in the healthcare setting include HIV, hepatitis and influenza (Emiliani, [4]).

The mode of reproduction varies depending on the type of virus. DNA virus replication often occurs within the nucleus, and is usually entirely dependent upon the host cells mechanisms for DNA and RNA synthesis. RNA virus replication occurs in the cytoplasm. These viruses contain their own RNA replicase enzymes and are therefore not dependent upon the host cell for genome replication. Reverse-transcribing viruses contain either ssRNA or dsDNA. These viruses reverse-transcribe their genomes using reverse transcriptase or polymerase enzymes and then incorporate their genome into the genome of the host cell. In all three cases, the virus is dependent upon the organelles of the host cell to encode proteins and lipids necessary for full viral reproduction (Dimmock, [5])

In the human body, viruses can spread by either or both of two mechanisms. The first of these mechanisms is cell lysis. The virus takes over the host cell and reproduces rapidly until the cell can no longer contain the large amount of viruses. At this point the cell ruptures, flinging the viruses outwards to infect other nearby cells. The second mechanism for viral spreading within the human body is less aggressive and less noticeable. A virus can remain latent within a host cell, reproducing itself without interrupting normal cell activities. The reproduced viruses can then exit the cell through budding of the cell membrane and infect other nearby cells. These viruses can remain latent and show no symptoms for a period of months or even years (Dimmock, [5]).

Fungi are a diverse kingdom of eukaryotic organisms that can come in a variety of shapes and sizes. The fungi that are relevant to healthcare settings, however, are usually single-celled fungi such as molds and yeasts. These organisms generally grow in dark, moist environments. Fungi can reproduce sexually through fruiting bodies – much like plants - or asexually through binary fission (splitting of a cell into two identical cells) budding or spores. Most molds

reproduce through spores, which cause a higher threat in healthcare settings due to their ability to travel long distances through the air.

Bodily fluids such as blood and vomit can act as a harbor for many infectious pathogens. These pathogens can survive much longer in a bodily fluid than they can on their own. As a result of this, bodily fluids are of great concern when it comes to contaminants in the healthcare setting. Bodily fluids can be transferred in a variety of ways, making it difficult to plan for, and protect against every possibility. Contaminants can be transferred by anything from arterial blood spray, to a minor failure in protective equipment, to an accidental needle stick.

Air pollution in the healthcare setting is a major source of concern. Extended exposure to polluted air can increase the risk of respiratory disease such as asthma and emphysema, as well as more serious conditions such as strokes. In ambulances, the major source of air pollution is the engine of the vehicle. This can emit high levels carbon dioxide, which can cause chronic respiratory disease with extended exposure. The engine also emits carbon monoxide, which can be fatal at relatively low doses due to its ability to block the oxygen-binding site on red blood cells. In hospitals, there can also be air pollution due to mercury and PVC. Mercury is used in many common medical devices such as thermometers and blood pressure cuffs. At room temperature, mercury can emit vapors that are extremely toxic to humans. PVC is a plastic that is commonly used in medical devices. PVC does not cause air pollution during regular use, but toxic dioxin vapors can be emitted during its incineration. This is a health hazard in hospitals that incinerate their materials on-site (The Environmental Protection Agency, [6]).

### 2.2.1 Sources of Contamination

Infectious pathogens originate from several sources, both human and environmental. The majority of pathogens in the healthcare setting originally come from human sources. In the

ambulance setting, human sources of pathogens include EMS personnel as well as patients from previous calls in the same ambulance. In some cases pathogens may originate from a human carrier that is asymptomatic (showing no symptoms), which is often the case for healthcare personnel. Due to the mildness or complete lack of symptoms, such people may unknowingly infect other people through direct or indirect transmission (Hall, C.B., [7]). Asymptomatic infections can spread to immunocompromised patients, where they can take advantage of the lack of defenses and become dangerous, opportunistic infections. Environmental sources of pathogens can come from a variety of places. Infected water, mold accumulation in ventilation systems and fungi from potted plant soil are a few examples of environmental pathogen sources (Lentino, J R et al. [8], Summerbell, R C et al. [9]).

### 2.2.2 Modes of Transmission

Pathogens can be transmitted through a variety of means. The type of transmission is dependent upon the pathogen that is considered. The factors that determine the mode of transmission of a pathogen include the site of infection, environmental conditions and the ability of the pathogen to survive *in vitro* (isolated from usual biological surroundings). Modes of transmission can include direct or indirect contact, droplet contact, airborne transmission, bloodborne transmission, and common vehicle transmission (food, water, equipment) (Bolyard, E A et al. [10]).

Direct contact transmission occurs when pathogens are transmitted from person to person without an intermediate medium. This can include, but is not limited to:

- Contact of a mucous membrane or an open wound with infected blood or other bodily fluids.

- Spread of spores through unprotected skin-to-skin contact.
- Transmission of mites from an infected patient to unprotected skin of a caregiver (Siegel, JD et al. [11]).

Indirect contact transmission occurs when pathogens are transmitted from an infected patient to an intermediate medium (gurney, medical instruments, healthcare personnel, etc.). This infection can then spread to another patient through contact with the contaminated surface. Examples of indirect contact transmission can include:

- Transmission of bodily fluids from patient-care devices after improper sterilization between patient care (Siegel, JD et al. [11]).
- Transmission of pathogens on the hands of healthcare professionals due to improper hand sanitation.
- Transmission of the influenza virus through infected respiratory aid devices after improper sterilization between patients (Bridges, C B et al. [12]).

Most methods of indirect contact transmission can be avoided through the proper use of personal protective equipment and the proper sterilization of the medical environment and equipment. Indirect contact transmission is a high risk in ambulatory care due to insufficient time to thoroughly sanitize between calls.

Droplet transmission occurs when the mucosa of a healthy individual comes in contact with infectious agents in mucous droplets from another individual. These droplets may be the result of coughing, sneezing, talking, or certain respiratory procedures (Bolyard, E A et al. [10]). The distance that droplets can travel through the air is dependent upon the size of the droplet. In most cases droplets travel a relatively short distance (~3-6 feet), although some pathogens have been known to cause infection through droplet transmission at longer distances (Siegel, JD et al.

[11]). Airborne transmission refers to the suspension of either infectious droplet nuclei or of microscopic spores (both are examples of aerosols). Relative to droplets responsible for droplet transmission (> 10 μm) droplet nuclei are very small (< 5 μg), allowing them to travel much farther distances to spread infection (Bridges, C B et al., [12]). Infectious aerosols are also capable of spreading through the ventilation systems of hospitals and ambulances. While ventilation systems can be filtered to lower the instance of infection, only isolation rooms have proven effective in preventing transmission through ventilation (Li, Y et al., [13]).

Common vehicle transmission refers to contact with previously contaminated items. Most environmental sources of pathogens transport through common vehicle transmission (the rest through airborne transmission). Examples of common modes of transmission of contaminants include (Bridges, C B et al. [12]):

- Ingestion of a contaminated water source
- Ingestion of a contaminated food source
- Ingestion of a contaminated medication
- Contact with contaminated devices or equipment

### 2.2.3 Common Pathogenic Diseases

Methicillin resistant staphylococcus aureus, also known as MRSA, is one of the more prevalent viral strains found in a healthcare setting. MRSA is a highly developed strain of this bacterial strain that has developed a resistance to beta-lactam antibiotics, which includes the penicillin variations. Found within the nasal passage, S.A. functions as part of normal skin flora in approximately 20% of all individuals and is transmissible via direct contact. MRSA can be dangerous in hospitals and medical facilities because it is an opportunistic pathogen that targets individuals with weak or compromised immune systems (People at Risk for Acquiring MRSA,

[14]). Many of the triggers that can weaken an immune system can be found in patients throughout the healthcare industry. Several catalysts for a weakened immune system include (Bolyard, [10]):

- Intensive treatment regimen e.g. Chemotherapy
- Malnutrition
- Advanced HIV infection
- Skin damage
- Fatigue
- Recurrent infections
- Newborn infants, and elderly patients

As is shown in Table 1 many antibacterial drugs can suppress a patient's immune system, providing a gateway for MRSA or other infections (Overview of Immunodeficiency Disorders, [15]). When patients in healthcare facilities contract MRSA infections they are generally severe because of the weakened immune response. Similarly, patients commonly contract infections in sensitive areas such as surgical wounds, catheter sites, IV injection sites, and burnt tissue.

**Table 1- Drugs That Cause Immunosuppression**

| **Class of Medication** | **Examples** |
|---|---|
| Anticonvulsants | Carbamazepine, diphenylhydantoin, lamotrigine, valproate |
| Calcineurin inhibitors | Cyclosporine, tacrolimus |
| Corticosteroids | Methylprednisolone, prednisone |
| Cytotoxic chemotherapy drugs | Multiple |
| Purine metabolism inhibitors | Azathioprine, mycophenolate mofetil |
| Rapamycins | Everolimus |
| Immunosuppressive immunogublins | Antilymphocyte globulin, antithymocyte globulin |
| Monoclonal antibodies | OKT3, basiliximab, daclizumab |

Tuberculosis (TB) is a fairly common, yet potentially life-threatening disease caused by the bacterial species *Mycobacterium Tuberculosis*. Mycobacterium Tuberculosis (M.T.) is highly aerobic and can be found in the respiratory tract of mammals. M.T. is transmissible through small droplets of fluid expelled from the body when sneezing, spitting, coughing or speaking, as represented in Figure 1. Each droplet expelled from the body has the potential to cause infection because the infectious dose is no more than 10 bacterial cells. Similarly, M.T. cells have a waxy coating, primarily comprised of mycolic acid, covering their surface, which allows them to remain alive in a dried state for weeks outside of an organic host (Young [16]). The ability of TB to remain alive outside of a host is especially striking when considering the effectiveness of standard cleaning procedures.

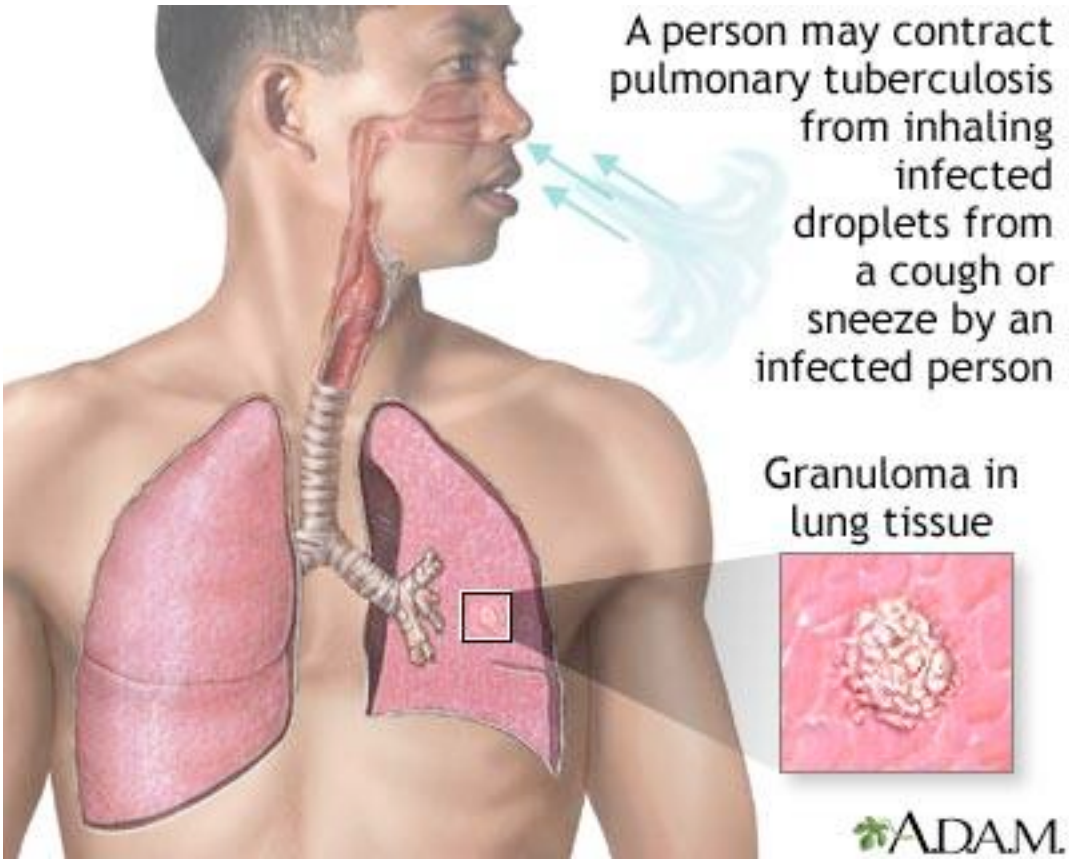


**Figure 1- Tuberculosis bacterium travel through the air and settles in the respiratory tract.**

The Human Immunodeficiency Virus (HIV) is an autoimmune disease that may lead to Acquired Immune Deficiency Syndrome (AIDS). Approximately 1,106,400 people in the United States are infected with HIV, and an estimated 20% do not know they are infected. In some urban areas, such as Washington D.C., 1 in 30 adults is HIV-positive (Katz, I. T., and Landovits, R J. [17]). The Hepatitis C virus (HCV) infects the liver and is the most common blood borne infection in the United States, affecting nearly 3.2 million people. HCV can easily spread, as 60%-70% of those newly infected are asymptomatic, showing few signs of any serious illness (HCV FAQs, [18]). This puts healthcare providers especially at risk for infection. They may be treating an infected patient without knowing they are at risk. Hepatitis C typically spreads when person comes in contact with the blood of an infected person. Blood spills even dried are

contagious because the hepatitis virus can survive outside the body for up to four days (HCV FAQs, [18]). This is why it is a necessity for EMS personnel to follow cleaning procedures, such as wiping up blood spill with one part bleach and ten parts water (HCV FAQs, [18]). Figure 2 outlines the various sources of hepatits C infection in the United States. Five percent of the total amount of documented cases is a result of contamination in a health care setting, This means that 160,000 people have contracted HCV while recovering in, or working in a healthcare facility.

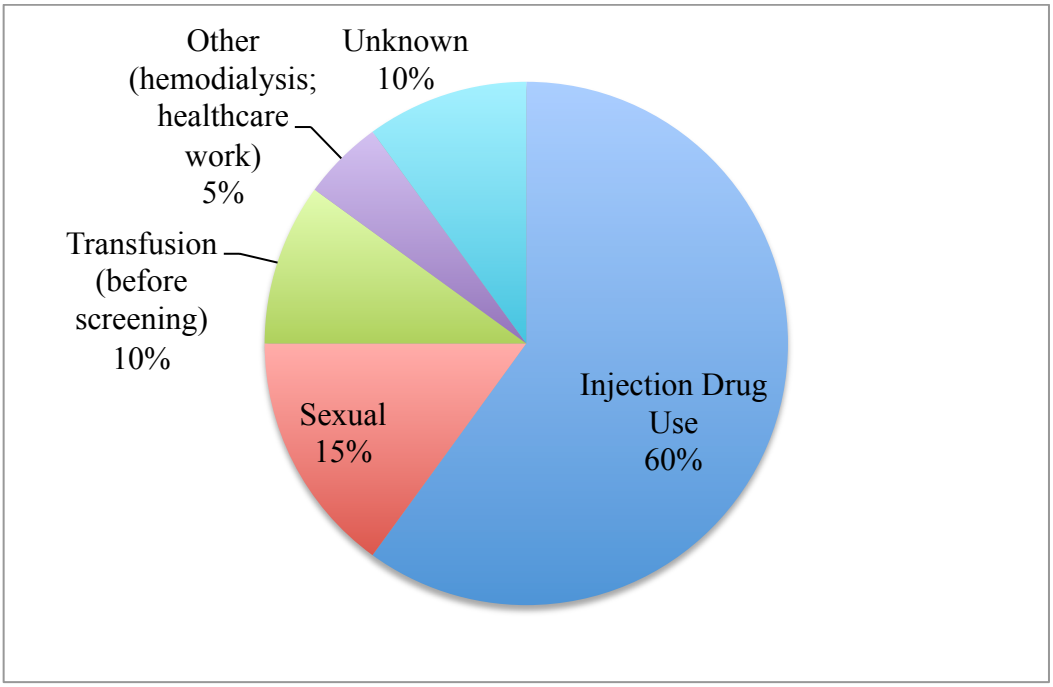


**Figure 2- Graphical representation of the source of hepatitis C infections.**

Influenza, or the flu, is a contagious respiratory disease caused by influenza viruses. When people cough, sneeze or talk, droplets transmit these viruses, as shown in Figure 3. Indirect transmission can also occur when someone touches a contaminated surface and then comes in contact with his or her mouth or eyes.

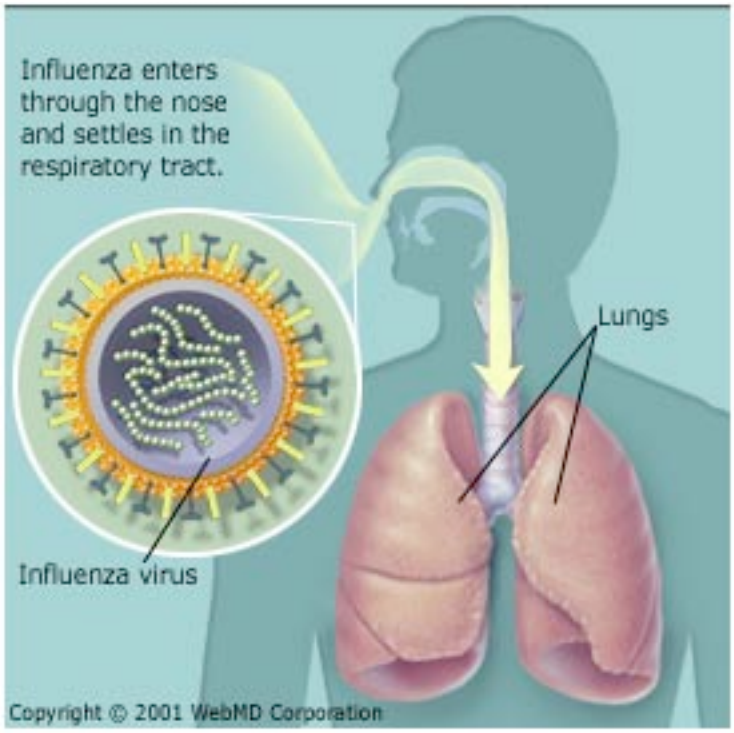


**Figure 3- The Influenza virus will supplant itself similarly to tuberculosis. A person can contract the Influenza virus through direct or indirect transmission.**

Two types of influenza viruses cause illness in people, influenza type A and influenza type B. Type A is divided into two subtypes based on proteins on the surface of the virus, hemagglutinin and neuraminidase (Seasonal Flu, [19]). These proteins are where abbreviations such as H1N1 (swine flue) come about. H1 describes the type of hemagglutinin and the N1 expresses the type of neuraminidase protein.

Since influenza is a virus it can be prevented with a vaccination. Vaccines use deactivated viruses to force the body to create antibodies that prevent against infection (Seasonal Flu, [19]). Each flu season a new vaccine is created to combat antigenic drift, which is small changes to the virus that make it undetectable by the body's immune system. Antigenic shifts can also occur, which is an abrupt change to the influenza virus (Seasonal Flu, [19]). Vaccines can be

administered two ways: via intramuscular shot or nasal spray. The impact of all these diseases is well documented throughout the healthcare system.

## 2.3 Documented Cases of Disease Exposure

One of the largest motivating factors for this project is the high number of nosocomial infections and deaths every year. Many of these deaths come about as a result of viral transmission between a patient and his/her care provider. Table 2 outlines the death rate of health care workers over a three-year period. Between 80 and 260 lives were ended due to contraction of diseases such as MRSA, tuberculosis, HIV, hepatitis C, and hepatitis B (Center for Disease Control and Prevention [20]). Working towards reducing occupational exposure to pathogens by re-evaluating current cleaning standards, utilizing 100% effective cleaning products, and implementing checks to ensure proper procedure is being followed can only help in the battle against deadly or harmful pathogens. The following sections contain information gathered from past studies and various literatures about documented exposures and decontamination method.

**Table 2- Occupational Deaths Among US Healthcare Workers (HCW), 2002**

| Cause of death | No. of deaths | HCW death rate, excluding support occupations (N = 6.2 million) | HCW death rate, including support occupations (N = 9.1 million) |
|---|---|---|---|
| Injury | 77–93 | 12–15 | 8–10 |
| Infection-related | 80–260 | 13–42 | 9–29 |
| Total | 157–353 | 25–57 | 17–39 |

In addition to the health hazard to patients and medical professionals, HAIs put enormous economic strain on the healthcare system. It has been estimated that the annual direct cost of HAIs to hospitals ranges from $28.4 – $33.8 billion (Scott [21]). Table 3 shows the annual cost of HAIs based on the site of infection.

**Table 3- Annual Cost of HAIs by Infection Site**

| | Number of Infections | Estimated annual cost using consumer price index for inpatient hospital (billions) |
|---|---|---|
| Surgical Site Infection | 290,485 | $3.45 - $10.07 |
| Central Line Associated Bloodstream Infections | 92,011 | $0.67 - $2.68 |
| Ventilator Associated Pneumonia | 52,543 | $1.03 - $1.50 |
| Catheter Associated Urinary Tract Infection | 449,334 | $0.39 - $0.45 |
| Clostridium Difficile Associated Disease | 178,000 | $1.14 - $1.62 |
| Other | 674,752 | Varies |
| **TOTAL** | 1,062,373 | $28.4 - $33.8 |

The most common forms of HAIs are surgical site infections and urinary tract infections caused by catheters. Surgical site infections account for a large portion of the direct medical costs to hospitals. If the rate of HAIs were decreased by 20%, it has been estimated that the healthcare system would save $5.7 - $6.8 billion. This is very significant when compared to the most costly diagnoses such as coronary artery disease ($17.8 billion), heart attack ($11.2 billion) and stroke ($6.7 billion) (Scott, R [21]).

### 2.3.1 MRSA

In September of 2004, the National Patient Safety Agency started the 'clean your hands' program which involved providing an alcoholic hand rub at patient care sites to prevent the spread of bacterial diseases such as MRSA (National Patient Safety Agency [22]). MRSA can be combated with a rigorous cleaning regimen using an alcohol and quaternary ammonium solution to effectively kill the bacterial cells. Despite these efforts, MRSA has not been eliminated from health care facilities. In 2007, the Georgetown University of Medicine and the University of Northern Colorado collaborated on a study testing for the presence of MRSA in a sample of ambulances operating throughout the western United States. Five specific areas were swabbed in 21 separate ambulances to test for MRSA contamination. Thirteen samples isolated from ten of the 21 ambulances tested positive for MRSA despite regular cleaning (Roline, C [23]). The significant quantity of bacterial colonies in these vehicles brought risk upon the EMS professionals and their patients. This may suggest that some viral or bacterial organisms are immune to modern cleaning methods, and could indicate that modern cleaning methods may not be thorough enough to combat these diseases.

In 2008, an article was written that expanded upon the idea that health care workers often acted as carriers of bacterial strains such as MRSA. Transmission of MRSA from health care professionals to their patients was tested through 106 studies. 27 patients tested positive for MRSA transmission, while another 52 cases considered transmission likely (Albrich, W, [24]). The prevalence of MRSA, although seemingly small, can lead to the infection of numerous patients from one source. The rate of MRSA infections becomes increasingly significant for immunocompromised patients because it can cause death if left to proliferate throughout the

body. Table 4 depicts the incidence of MRSA infections in health care workers at the hospital versus non-hospital facilities.

**Table 4- MRSA Infections of HCWs in Hospital vs. Non-Hospital**

| | **Number of healthcare workers with MRSA** | **Number of healthcare workers tested** | **Prevalence of MRSA in healthcare workers** |
|---|---|---|---|
| Hospital | 1404 | 25884 | 5.4% |
| Non-Hospital | 42 | 1236 | 3.4% |
| **Total** | 1446 | 27120 | 5.3% |

The data suggests that healthcare workers are most likely to become infected with MRSA at the hospital than elsewhere. The likelihood of a healthcare worker to become infected varies within locations of the hospital. The study evaluated the intensive care unit, general ward and the burn unit. Table 5 illustrates that healthcare workers are most likely to be infected with MRSA in the general ward. General preconceived notions would be for more infections in the intensive care unit that the general ward. MRSA infection rates also vary with geographic location, as depicted in Table 6.

**Table 5- MRSA Infections in Different Hospital Wards**

| | **Number of healthcare workers with MRSA** | **Number of healthcare workers tested** | **Prevalence of MRSA in healthcare workers** |
|---|---|---|---|
| Intensive Care Unit | 154 | 3309 | 4.7% |
| General Ward | 128 | 2032 | 6.3% |
| Burn Unit | 38 | 1326 | 2.9% |
| **Total** | 320 | 6667 | 4.8% |

Africa and East Asia reported the highest percent of MRSA infections. This could suggest that the method for cleaning hospitals is not as effective in these locations. Western Europe had the largest number of healthcare workers tested, but one of the lowest prevalence percentages. This could suggest that Western European healthcare workers have the greatest awareness of MRSA prevention.

**Table 6- MRSA Infections of HCWs Based on Geographic Location**

| | **Number of healthcare workers with MRSA** | **Number of healthcare workers tested** | **Prevalence of MRSA in healthcare workers** |
|---|---|---|---|
| Northern Europe | 101 | 1920 | 5.3% |
| Western Europe | 291 | 10851 | 2.7% |
| Southern Europe | 151 | 3121 | 4.8% |
| Eastern Europe | 8 | 511 | 1.6% |
| North America | 328 | 7886 | 4.2% |
| South America | 13 | 201 | 6.5% |
| Africa | 105 | 678 | 15.5% |
| Middle East | 136 | 2233 | 6.1% |
| South and Central Asia | 17 | 513 | 3.3% |
| East Asia | 132 | 1005 | 13.1% |
| Australia, New Zealand | 196 | 2017 | 9.7% |
| **Total** | 1478 | 30936 | 4.8% |

The age group of the patients being aided to by healthcare workers will affect the likelihood of receiving MRSA. The study compared infections amongst workers aiding adults, elderly adults (geriatrics) and children (pediatrics). Table 7 shows that geriatric workers had the highest percent of MRSA infections. This seems appropriate since elderly adults are more likely to receive an infection than younger adults because of their weakening immune systems. For further reference of the data, see Appendix A.

**Table 7- MRSA Infections of HCWs Based on Patient Age Group**

| | **Number of healthcare workers with MRSA** | **Number of healthcare workers tested** | **Prevalence of MRSA in healthcare workers** |
|---|---|---|---|
| Adults | 601 | 12888 | 4.7% |
| Geriatrics | 50 | 946 | 5.3% |
| Pediatrics | 111 | 3187 | 3.5% |
| **Total** | 762 | 17021 | 4.5% |

### 2.3.2 Tuberculosis

In 2002, two Welsh scientists conducted an investigation of the contamination levels in emergency ambulances, and the effectiveness of standard cleaning protocol. Several key sites were chosen for testing including;

- Folds in stretcher mattress
- Off side wall-head end off stretcher mattress
- Inside cupboards or drawer corners
- Steering wheel
- Inside Entonox mask
- Inside suction bottle
- Rails of grid/track, or floor if no track.

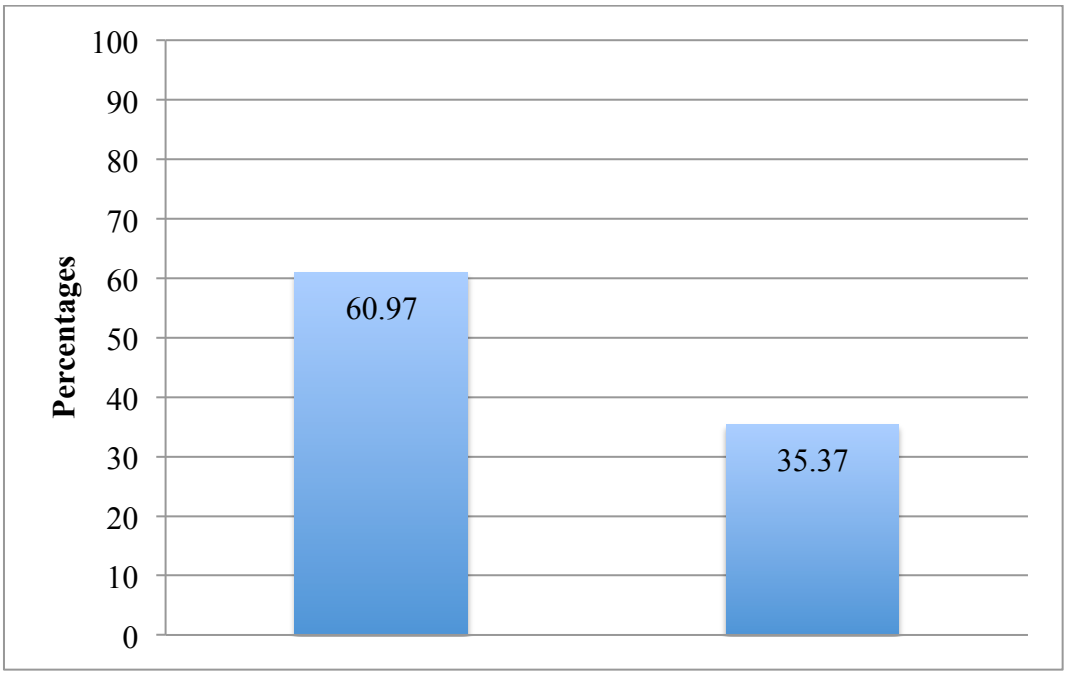


**Figure 4- Graph representing percent of contamination on the test sight before and after cleaning.**

Figure 4 depicts the percentage of contamination within the tested sites before and after standard cleaning of the ambulance (Cutter, J [25]). Cleaning did little to sterilize the cabin and, in several areas, bacterial colonies were transferred to previously uncontaminated locations within the ambulance. Contamination found on several of the key locations can result in direct transmission on many bacterial strains, including TB (Cutter, J [25]). The presence of M.B. within the entonox mask, among other areas, would certainly result in infection. Table 8 depicts the various sources of TB infection in ambulance operators. The majority of infections are transmitted through sputum droplets coughed up from patients (Young, S [16]).

**Table 8- Source of Infectious Diseases in Ambulance**

| Source | TB Levels | TB Prevalence | MRSA Levels | MRSA Prevalence | VRE Levels | VRE Prevalence |
|---|---|---|---|---|---|---|
| Blood, peripheral | 1 | 0.3% | 138 | 8.8% | 24 | 6.0% |
| Blood, central catherter | 0 | 0.0% | 68 | 4.3% | 15 | 3.8% |
| Broncho-alveolar aspiration | 21 | 7.1% | 274 | 17.5% | 2 | 0.5% |
| Endotracheal aspiration | 21 | 7.1% | 274 | 17.5% | 0 | 0.0% |
| Sputum | 178 | 60.5% | 333 | 21.2% | 0 | 0.0% |
| Nasopharynx, oral | 2 | 0.7% | 86 | 5.5% | 0 | 0.0% |
| Urine, catheter | 0 | 0.0% | 21 | 1.3% | 23 | 5.8% |
| Urine, clean-voided | 3 | 1.0% | 79 | 5.0% | 64 | 16.1% |
| Stool | 1 | 0.3% | 0 | 0.0% | 29 | 7.3% |
| Rectal Swab | 0 | 0.0% | 0 | 0.0% | 158 | 39.7% |
| Wound, abscess | 16 | 5.4% | 225 | 14.3% | 30 | 7.5% |
| Skin | 2 | 0.7% | 49 | 3.1% | 5 | 1.3% |
| Tissue | 15 | 5.1% | 28 | 1.8% | 4 | 1.0% |
| Body Fluid | 21 | 7.1% | 66 | 4.2% | 18 | 4.5% |
| Total | 294 | 100% | 1569 | 100% | 398 | 100% |

The high incidence of disease presented in these studies stresses the importance of effective cleaning as the primary line of defense against infection. Unfortunately, many areas throughout the world do not have access to proper sanitation methods, which leads to approximately 1.5 million TB related deaths per year (Young, S [16]).

## 2.4 Decontamination

There are a variety of cleaning agents used in the healthcare setting. It is essential to properly clean all medical equipment to ensure that no infections are transmitted. Ambulances and hospitals are exposed to a plethora of pathogenic bacteria and viruses that result in millions of infections each year. To ensure a safe healthcare environment, guidelines for cleaning protocol of different instruments should be followed. The CDC has adopted a system for decontamination process based on severity of contaminant and the surface it resides. To understand the system, definitions of decontamination practices must be defined.

### 2.4.1 Definitions of Decontamination

The CDC has clearly defined the differences in decontamination practices, to distinguish the type of agent needed for proper pathogen suppression. The defined components of decontamination are:

- Cleaning: the removal of visible soil (e.g., organic and inorganic material) from objects and surfaces and normally is accomplished manually or mechanically using water with detergents or enzymatic products.
- Disinfection: process that eliminates many or all pathogenic microorganisms, except bacterial spores, or inanimate objects.
- Sterilization: process that destroys or eliminates all forms of microbial life, including bacterial spores (source for references).

Dr. Earle H. Spaulding, a former microbiology professor from Temple University, was one of the world's leading researchers in microbial disinfectants. The CDC follows an approach developed

by Dr. Spaulding for prioritizing instrument contaminant removal by severity. His approach breaks down into three categories: critical, semi-critical, and noncritical. These classifications are based on the degree of risk of infection, depending on the use of the instrument. This allows healthcare employees to more readily determine how to properly disinfect or sterilize their equipment. These classifications are defined as:

- Critical: items that will enter tissue or vascular system
- (High-level) Semi-critical: items will contact mucous membrane or non-intact skin
- (Intermediate-level) Semi-critical: some semi-critical items and non-critical items
- Non-critical: items that will contact intact skin

All items described as critical or high-level semi-critical must be sterilized. All intermediate-level semi-critical or non-critical items should be disinfected. Refer to Appendix B for the complete list of sterilization and disinfection methods.

### 2.4.2 Decontamination Methods and Chemicals

Cleaning should occur before disinfection and sterilization because it allows both to become more efficient. Pre-soaking contaminated instruments with a cleaning solution helps inhibit blood and bodily fluids to dry on the surface. Generally, the area most contaminated should be cleaned last to prevent spreading to cleaner areas. It is common in a health care environment to start with the cleanest area first (McDonnel, G., and Russell, A., [26]). Starting with the least contaminated areas will isolated the most contaminated areas and contains their ability to spread.

For cleaning instruments, it is suggested to use a relatively neutral pH detergent to achieve the most effective compatibility to soil removal. Some solutions with added enzymes, like proteases, are used to aid the removal of organic materials from a surface (Rutala, W. and Weber, D., [27]). The main function of proteases is to catalyze metabolic functions. A metabolic pathway will break molecules into smaller sub-units, like breaking down the organic molecules of infected blood. When using enzymatic cleaners, it is necessary to follow instrument manufacture instructions to ensure good health and safety. They must be properly diluted in the solution because high concentrations can lead to allergic reactions and irritation (Hutchisson, B. and LeBlanc, C., [28]). Alkaline-based detergents can also be used, but enzymatic solutions are usually suggested since alkaline-based detergents can be corrosive on certain materials. Studies have shown that enzymatic solutions are more effective than strictly neutral-pH detergents, since they are more compatible with different metal materials (Merritt, K., Hitchins, V., and Brown, S., [29]).

EMS personnel use different types of mechanical cleaners for soil removal. Ultrasonic cleaners produce waves of acoustic energy that travel through the solution and break bonds. The solution will experience cavitation, the formation and implosion of small bubbles. The acoustic waves will subject the liquid to rapid changes in pressure, creating the bubble cavities in low-pressure locations. Ultrasonic cleaners are not considered antibacterial, but the propagated waves generate an increase in killing power of a detergent (Jatzwauk, et al. [30]). Figure 5 is an example of an ultrasonic cleaner manufactured by LeelaSonic. LeelaSonic manufactures surgical instrument cleaners and dental cleaning equipment.

**Figure 5- An ultrasonic instrument leaner by LeelaSonic**

Another mechanical system used for soil removal is a washer-decontaminator. Washer-decontaminators are computer-controlled units that act like a dishwasher. The units circulate heated water and detergents to remove surface soils. EMS personnel are not limited to using mechanical or automated machines for contaminant cleaning. Manual cleaning is necessary for delicate instruments and hard to reach places through rapid scrubbing and fluid pressure.

Disinfectants are typically alcohol or chlorine-based substances. Alcohols are considered to be bactericidal, tuberculocidal, fungicidal, and virucidal, meaning they can kill bacteria, mycobacterium, fungi, and viruses (Rutala, W. and Weber, D., [27]). The most common alcohols used for disinfection are ethyl alcohol and isopropyl alcohol. Ethyl alcohol is a very

effective virucidal agent, having the ability to inactivate all lipophilic (fat dissolving) viruses and most hydrophilic (water dissolving) viruses (Klein, M. and DeForest, A., [31]). In 1964, Dr. Spaulding conducted a series of tests comparing the tuberculocidal effect of different alcohols. Ethyl alcohol was found to kill the M. tuberculosis bacteria in a matter of 15 seconds (Spaulding, E., [32]). Alcohols can't be sterilizers since they cannot kill bacterial spores or disrupt heavily rich proteins. Medical instruments that can be disinfected from alcohols include thermometers, stethoscopes, endoscopes, and vaccine bottles. 70% alcohol swabs and wipes are commonly used for surface disinfection.

The most commonly used chlorine compounds for disinfection are hypochlorites. Sodium hypochlorite is one of the main ingredients in household bleach, accounting for approximately 5.25-6.15% of the solution (Rutala, W. and Weber, D., [27]). Hypochlorites can be used for spot-disinfection, especially for blood spills. However, hypochlorites are not always used since they are corrosive and toxic. Compounds like chlorine dioxide and sodium dichloroisocyanurate can be used since they retain chlorine longer in a reaction, creating a more sustained bactericidal effect (Rutala, W. and Weber, D., [27]). Studies show that low concentrations of chlorine have the ability to kill bacteria, while high concentrations can kill M. tuberculosis and spores. Unlike alcohols, chlorines have the ability to kill spores. Table 9 is representative of required procedures for disinfecting semi-critical and non-critical items. Ethyl/isopropyl alcohol and sodium hypochlorite require at least one minute of exposure to the contaminated surface for proper disinfection.

**Table 9- Methods of Disinfection for Semi-Critical and Non-Critical Items**

| Object | Procedure | Exposure Time (min) |
|---|---|---|
| Smooth, hard surface | Ethyl or isopropyl alcohol | ≥1 |
| | Sodium hypochlorite | ≥1 |
| Thermometers and hinged instruments | Ethyl or isopropyl alcohol | ≥1 |

There are a few methods of preforming sterilization. Hot steam treatment is one of the more common methods of sterilization. It is so widely used since it is nontoxic and inexpensive. Steam is emitted at the top of a sterilization chamber and forces the heavier air through the vents. This creates direct steam contact on the item being sterilized. The four distinct parameters of effective sterilization are steam, pressure, temperature, and time. The increase in pressure will increase the temperature, thus decreasing the time needed to sterilize the item. Steam sterilizers are categorized into two types: gravity displacement systems and prevacuum systems.


**Figure 6- Prevacuum Autoclave by Tuttnauer**

Gravity displacement systems (autoclaves) are generally set at 121ºC (250ºF), while prevacuum systems (as shown in Figure 6) are generally set at 132ºC (270ºF). These temperatures must be maintained in order to ensure microorganism eradication on the instrument. For instance, in the case of wrapped instruments, the steam exposure time in a gravity displacement system is approximately 30 minutes. Whereas for prevacuum systems, the necessary steam exposure time for wrapped instruments is only 4 minutes (Rutala, W. and Weber, D., [27]).

Prevacuum systems work more efficiently sterilizing porous media than gravity displacement systems do. Gravity displacement systems are not used for this purpose since they cannot completely remove all of the air out of the sterilization chamber. Any remaining air in the chamber or load will impede steam infiltration of the media (Rutala, W. and Weber, D., [27]). Prevacuum systems have an advantage over gravity displacement systems since they use vacuum pumps to remove all air from the sterilization chamber and waste load before steaming even begins. Thus, gravity displacement systems are more suitable for nonporous media. The

duration of steam exposure still ultimately depends on the type of item being sterilized and the type of sterilizer being used. Table 10 outlines necessary steam exposure time for different items, based on sterilizer type. According to the CDC, steam sterilization should be used all critical and semi critical items that are heat resistant (Rutala, W. and Weber, D., [27]). Healthcare facilities use steam sterilizing to clean waste and sharps containers, which fill with microorganisms.

**Table 10- Minimum Steam Exposure Cycle Times**

| Type of sterilizer | Item | Exposure time at 250ºF (121ºC) | Exposure time at 270ºF (132ºC) | Drying time |
|---|---|---|---|---|
| Gravity displacement | Wrapped instruments | 30 min | 15 min | 15-30 min |
| | Textile packs | 30 min | 25 min | 15 min |
| | Wrapped utensils | 30 min | 15 min | 15-30 min |
| Dynamic-air-removal (e.g., prevacuum) | Wrapped instruments | | 4 min | 20-30 min |
| | Textile packs | | 4 min | 5-20 min |
| | Wrapped utensils | | 4 min | 20 min |

Alternative methods to heat-steam treatment include using ethylene oxide gas and low-temperature sterilizers, like ozone. Table 11 is representative of necessary procedure exposure for sterilizing semi-critical and critical items. As stated earlier, heat steam sterilization requires 3-30 minutes of exposure to the contaminated surface at 121-132ºC to achieve proper sterilization. Ethylene oxide gas and hypochlorite are not require to be at high temperatures like heat steam sterilization, but the exposure time for ethylene oxide gas is significantly longer than the exposure time for heat steam and hypochlorite. Ethylene oxide gas typically will take 1-6

hours to process, then an additional 8-12 hours to aerate. It is emphasized that the procedure operator follows the manufacturer's recommendation for temperature and exposure time.

**Table 11- Methods of Sterilization for Critical and Semi-Critical Items**

| **Object** | **Procedure** | **Exposure Time (min)** | **Temperature (ºC)** |
|---|---|---|---|
| Smooth, hard surface | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |
| Rubber tubing and catheters | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |
| Polyethylene tubing and catheters | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |
| Lensed instruments | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |
| Thermometers and hinged instruments | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |

### 2.4.3 Current Ambulance Cleaning Protocol

It is a necessity for EMS personnel to routinely clean the ambulance. The United States Department of Health and Human Services have developed guidelines for proper cleaning practices for EMS ambulance unit, as listed below:

1. EMS agencies should clean and disinfect non-patient-care areas of an ambulance such as the driver's compartment according to the vehicle manufacturer's recommendations. These areas of the vehicle may become unintentionally contaminated by the ambulance staff touching the steering wheel with a contaminated glove.

2. Ambulance staff should wear non-sterile, disposable gloves that are compatible with the types of detergent and disinfectant used while handling the cleaning solutions and when cleaning the ambulance surfaces. Used gloves should be disposed in a sturdy leak-proof bag if they become damaged, soiled, or after cleaning is complete. Used gloves should never be washed or reused. All personnel should avoid activities that may generate infectious aerosols while cleaning the interior of an ambulance, and the staff should wear eye protection such as a face shield or goggles if splashing is expected.

3. Frequently contaminated surfaces in patient-care compartments are identified including stretchers, railings, medical equipment control panels, adjacent flooring, walls, ceilings, work surfaces, door handles, radios, keyboards, and cell phones. These surfaces can be directly contaminated with respiratory secretions, aerosols, and other bodily fluids during patient care, or indirectly contaminated by touching the surfaces with gloved hands. Periodically, these areas should be cleaned with detergent and water, and then disinfected using an EPA-registered hospital disinfectant according to its instructions. It should be noted that some manufacturers recommend cleaning their electronics only by wiping the

housing with a soft cloth dampened with a mild detergent and water to avoid disinfecting or cleaning solutions oxidizing the circuitry through corrosion.

4. For non-porous surfaces in patient-care compartments that are not frequently touched, detergent and water are sufficient for cleaning the surfaces. Cleaning methods that can potentially produce aerosols or mists should be avoided in the patient-care areas.

5. For small spills of bodily fluids, clean with detergent and water, and then disinfect using a hospital disinfectant in accordance with the manufacturer's instructions. Large spills of bodily fluids should be cleaned by removing any visible organic matter with absorbent material, then cleaned and disinfected using the same procedures.

6. Contaminated reusable patient care devices and equipment should be placed in biohazard bags labeled for cleaning. The devices and equipment should be disinfected or sterilized according to the manufacturer's instructions.

7. After cleaning, properly dispose used gloves then clean hands with soap and water or an alcohol-based hand gel. The ambulance staff should avoid touching the face with gloved or unwashed hands.

From the guidelines it is recommended that healthcare facilities routinely practice procedure for infection control. It is also suggested that all personal protective equipment are FDA (Food and Drug Administration) approved and regulated. Items like disposable gloves must be removed of properly to avoid further contact with contaminated material. Gloves should also be disposed of when another procedure is about to be performed. Figure 7 demonstrates the proper procedure to removing disposable gloves.

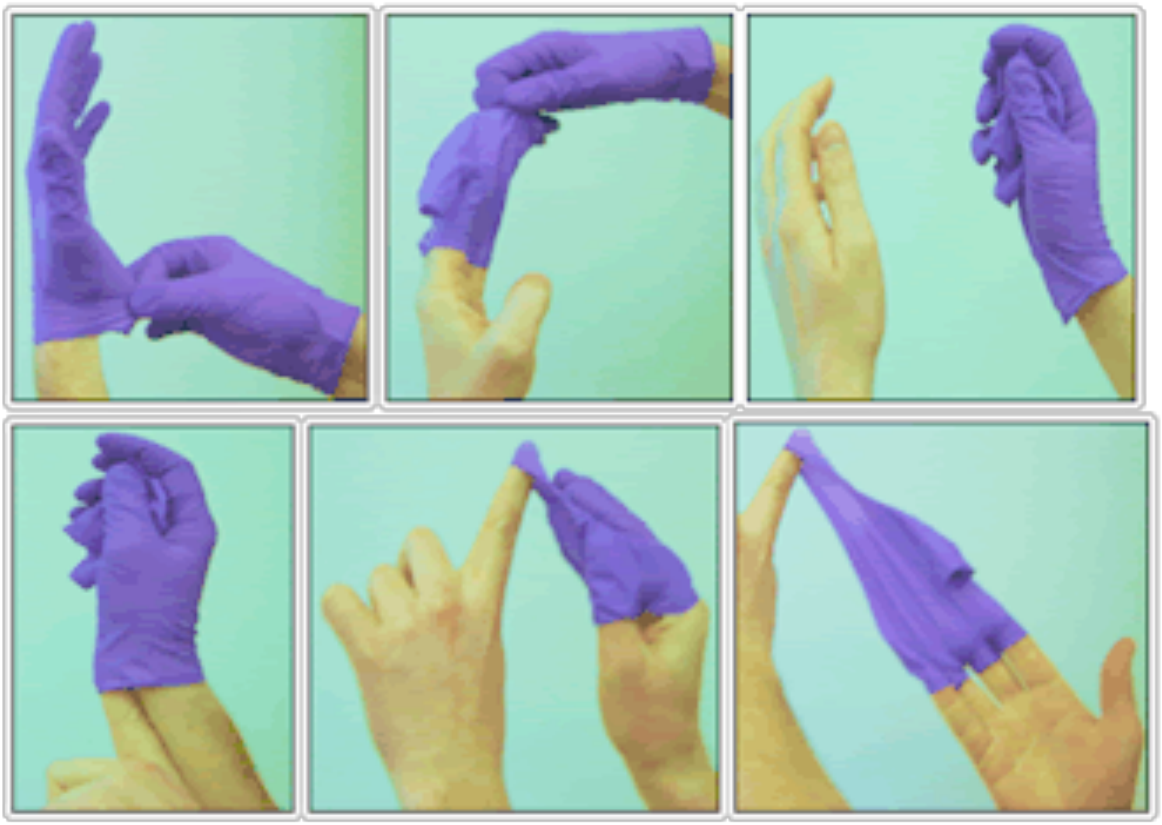

**Figure 7- Demonstration of Proper Removal of Disposable Gloves**

In the fourth step of glove removal process, by inserting two uncontaminated fingers, the edge of the glove should be turned out, so the uncontaminated side of the glove is exposed. Contaminated gloves and other contaminated disposable devices should be placed in labeled

biohazard bags to better contain any pathogens. Figure 8 shows a standard biohazard bag that contaminated disposable items can be discarded in.


**Figure 8- Biohazard Bag for Waste Disposal**

Sanitation standards are implemented to reduce and eliminate the transmission of pathogens between surfaces, patients, and health care workers. The current standards dictated by the National Fire Protection Agency (NFPA) detail every component of an ambulance, and the necessary hardware to ensure the safety of both the patient and the care providers. The

importance of effective and efficient cleaning methods has been, and will continue to increase with the rapid development of multi-drug resistant organisms. Each year in the U.S., there are millions of reported cases of health care associated illnesses, which kill hundreds of thousands of people.

The NPSA has quantified their standards, outlining the specific cleaning method and desired outcome to eliminate any possibility of contamination. Specifically, the standards focus on items that come in constant contact with patients such as stretchers, head stabilization blocks, and passenger seats. The standards for items commonly found on ambulances can be seen below.

Virox Technologies, a Canadian company that focuses on chemical disinfectants, has outlined proposed standards for maximum sterility. The standards begin by outlining the different classifications of contaminated equipment. Non-critical devices such as pressure cuffs that have not come into contact with a mucous membrane are considered low risk for contamination. Although not critical, these items could lead to secondary infections through direct contact with skin. Critical and semi-critical instruments are to be isolated as soon as possible after use. They should remain sealed off until transit back to the station or hospital is complete. Once back, any dirtied instruments are thoroughly cleaned, and then disinfected using any one of several liquids. Virox recommends several different chemicals for different levels of contamination. To effectively clean and disinfect a critically contaminated instrument, Virox recommends the use of and Accel wash detergent. This solution is capable of sterilizing instruments covered in bodily fluids, both wet and dry, such as blood or sputum.

# CHAPTER 3. CONTAMINATION CONTROL SOLUTIONS

## 3. Introduction

The healthcare system is divided into two major components, pre-hospital care and hospital care. Pre-hospital care is primary done by emergency medical ambulances, which provide care to patients and transport them to the hospital for primary care. Like most of the healthcare system, ambulances are almost continuously in use. This high usage results quick turnover and little time for proper cleaning technique. However, ensuring that ambulances, and hospitals are clean and free of contaminants is essential to the goals of the healthcare system.

Pathogens and hazardous contaminants are found commonly in our everyday lives. Even a simple cough from a fellow passenger on a train could transmit contaminants with pathogens for everything from the common cold to tuberculosis. Due to this it is hard to identify potential threats and thus standard precautions must be used to combat these pathogens. These standards are difficult to enforce but are critical in maintaining a contaminant free environment. For example, New York City has made Zolatone, a clean surface material, standard in all the city's emergency vehicles.

Another aspect of maintaining a clean, safe environment is a being able to identify pathogens quickly and correctly. Biosensors have been developed to detect pathogens and have been used in hospitals throughout the country but have seen limited use in ambulances due to their inefficiency. A fast system is required in ambulances since they have such a high turnover rate.

Lastly, cleaning procedures ensure that pathogens, identified or not, are eliminated and a clean environment is maintained in the healthcare system. By evaluating current procedures,

methods of cleaning and substances used to clean, improvements can be made to combat newly developing highly resistant pathogens.

Part of the background research done for this project was speaking with actual EMS professionals to develop an understanding of their first-hand experiences and some of the limitations they face in their average day at work. Our group visited the Worcester ambulance depot and was given the opportunity to observe the Braun ambulance present on campus. Neil Blackington, of Boston EMS, provided our group with vital insight into the Braun ambulance cabin features during his visit. Some of the questions prepared for these visits include:

1) How long on average does it take to clean the ambulance?
2) Is any protective equipment required when using cleaning solutions?
3) What is the most common contaminant problem encountered (blood, human waste)?
4) What cleaning solutions do you use?
5) How often are stretchers, stretcher mattresses, and other restraint devices cleaned?
6) Is there any equipment that does not get cleaned after each run?
7) What compartments are most difficult to clean in the ambulance?
8) What're common problems faced during the cleaning process?

Through these discussions with healthcare professionals we learned valuable information about the current cleaning process and its limitations. We learned about major areas of concern for decontamination. These areas include seat cushions, railings, and radio equipment. All of these regions are in constant use and thus constant exposure to contaminants. Some of them, such as the radio equipment, have small spaces that are difficult to clean.

Many of the devices, such as the KED, and surfaces in the ambulance are made of materials that do not absorb contaminants, such as blood, and therefore much easier to clean up. Items that do absorb contaminants, like straps or seat belts, can all be removed and washed, or disposed of and replaced if necessary.

Paramedics are responsible for cleaning their ambulance at the end of their shift, though some do opt to clean it after every run. Some paramedics use a power washer hose to rinse out their vehicles at in between calls. The thoroughness of the cleaning is up to the discretion of the paramedic. Depending on how much time they have between run, the paramedics may not clean up to standards, with only the major areas receiving cleaning. One of the individuals we spoke to described how he wore gloves but no other form of Personal Protection Equipment. While these visits focused mostly on ambulances, much of the insight gained from our observations and discussions can be applied to the hospital setting.

## 3.1 Zolatone

The many surfaces within an ambulance or hospital have impurities that allow for pathogens to harbor. A durable, scratch-free coating is required to laminate these surfaces. Scratches and imperfections in the surface allow for contaminants to evade disinfection and possibly spread to the patient or healthcare provider. For over sixty years ambulance manufactures have made Zolatone the coating of choice for this purpose. New York City actually specifies that Zolatone is the only coating to be used in their emergency vehicles (Zolatone, [32]).

### 3.1.1 Background

Zolatone is a polychromatic, modified nitrocellulose coating with a background color and accenting color flecks that provides a durable and decorative coating. It is abrasion, scratch, and chip resistant. Cleaning can be done easily with common products. Zolatone is suitable for application on (Zolatone Technical Specs, [33]):

- Aluminum and fiberglass boat interiors
- Trucks beds and boxes
- Interior compartments on fire trucks, ambulances, utility trucks, safety vehicles and armored cars
- Industrial equipment
- Aircraft or bus interiors and compartments
- Light fixtures
- Safes
- Furniture and shelving

Zolatone is applied in a three-step process. First, cleaning, sanding and eliminating rust prepare the surface. Next a primer coating is sprayed on, followed by the Zolatone. A catalyst is available to be mixed in with the Zolatone that will greatly increases water, chemical and abrasion resistance without losing any adhesion or impact resistance. The coatings are easy to apply using a pressure sprayer and will dry overnight.

While Zolatone has achieved widespread use amongst ambulances manufactures, its use in hospitals has not reached its full potential. There are very few mentions of hospitals in any

literature about Zolatone. Its durability and scratch resistance would be extremely useful for preventing pathogens from evading disinfection.

## 3.2 High Efficiency Particulate Air Filters

Airborne pathogens are responsible for millions of infections and deaths each year. The droplets can be expelled into the air from coughing, sneezing or talking. Diseases like influenza and tuberculosis are common airborne threats in the healthcare system. The ventilation system in an ambulance must also filter any exhaust that enters the cabin. Vehicle exhaust is comprised of harmful compounds like carbon oxides that are by products of a combustion reaction. Extended exposure of carbon dioxide can cause chronic respiratory disease. Carbon monoxide will block the oxygen-binding site on red blood cells until the person is deprived of oxygen.

### 3.2.1 Background

There are many methods to reduce the chances of airborne infection. One of the most efficient of these methods are High Efficiency Particulate Air (HEPA) filters, which can trap particles as small as 0.3 microns and filter out 99.99% of contaminants (Danforth, [34]). Unlike membrane filters, which act like a sieve allowing particles smaller than the largest opening to pass, HEPA filters use densely compacted fiberglass to trap particles in three ways (Figure 9):

1. Interception- Particles are impacted on the fiber mesh and stick on to it.

2. Impaction- Larger particles collide with the fiber mesh and are retained within the strands.

3. Diffusion- Smaller particles collide with surrounding gas molecules and their velocity is reduced.

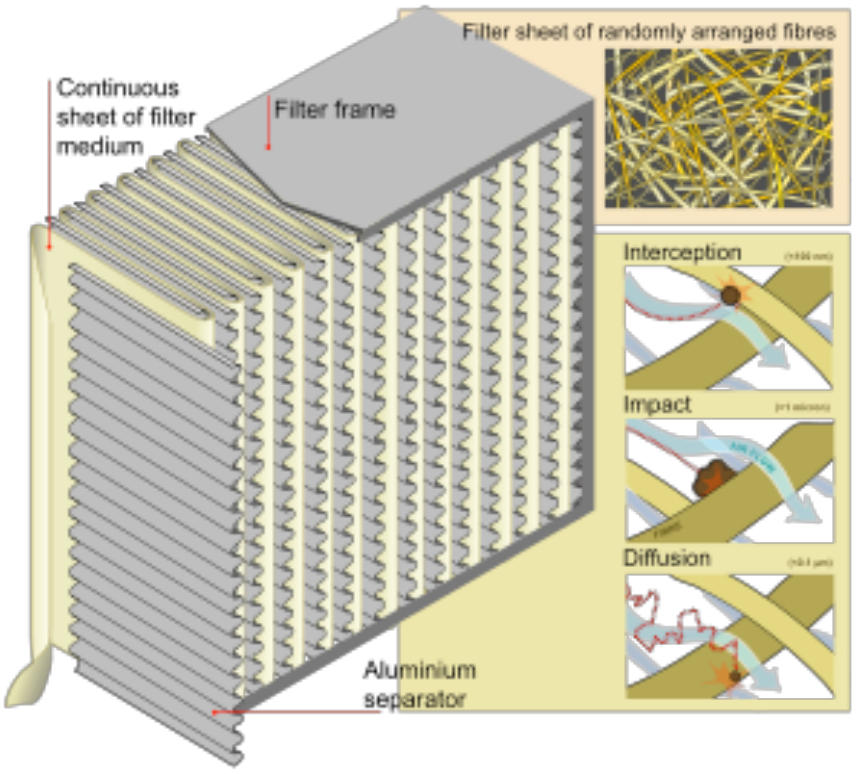


**Figure 9- The structure of a HEPA filter. Models of interception, impact and diffusion are illustrated.**

An important aspect of HEPA filter system design incorporates routine maintenance with scheduled in-situ testing of filters, gaskets, and housing. Over time contaminants will accumulate in the filter and it will need to be cleaned. This is relatively simple process, in which a soft brush is used to wipe out the fiberglass strands. Using a hard brush will cause the strands to tear and result in decreased efficiency ("How HEPA Filters Work" [35]). Particles that cannot be brushed out can be blown out using highly compressed air. The filter is then left to soak in germicidal solution, to ensure that it is completely disinfected before being reused.

### 3.2.2 Analysis

HEPA filters are already widely used in the healthcare system, mainly in two ways: masks and ventilation systems. Masks provide personnel HEPA filters to individuals, whether it is the healthcare providers or infected patients. For example, patients with active tuberculosis, or other airborne diseases may wear a HEPA mask to prevent the spread of pathogens.

Hospitals and ambulances make use of HEPA filter in their ventilation systems. This concept comes from the airline industry, where the air recirculation through a plane has to be clean and pathogen free (DOE Specifications, [36]). Ambulances and hospitals make use of these systems to provide clean air and to prevent large-scale outbreaks. Environmental contaminants can enter the clinical environment by exogenous (outside source, i.e. ventilation) and endogenous (inside source, i.e. personnel) sources (DOE Specifications, [36]). "Dual utilization" of HEPA filtration is necessary to control airborne contaminants. HVAC HEPA filter systems remove exogenous contamination from the air, while free-standing (recirculating) HEPA Air Purification units to remove endogenous contaminants (Danforth, [34]).

## 3.3 Ozone Laundry

The soiled laundry from the healthcare system presents unique challenges in cleaning, as many types of soil loadings occur on a continuous basis. Hospital and ambulance cleaning staff must routinely wash linens contaminated with blood, mucus, urine, bacteria, and viruses (Laundry Consulting, [37]). The high volume of laundry the staff must handle can pose complications in laundering. Using traditional laundering methods, 3 gallons of water are used for each pound of linens, seventy percent of which is heated. Generally, incoming water temperature is 60-degrees and must be heated to 160-dgrees and 8.33 Btu's to heat one gallon of water one degree. Thus, for a 1,000 lb. load of linens, 3,000 gallons (2,100 gallons of which are heated) of water are used, as well as 1,749,300 Btu's (REF). The typical amount of energy required to dry linens is equivalent to the energy required to heat the water. This creates financial and environmental dilemma for hospitals. Another environmental cost of typical laundry systems is the large amount of chemicals, such as alkali, acid, bleach and various detergents, that are used in the cleaning process. Further, the energy required in operating a hospital results in large emissions of carbon oxides into the atmosphere. All of these factors add up to a large financial and environmental burden on the healthcare system.

### 3.3.1 Background

A more efficient laundry system, known as Ozone Laundry, can reduce the environmental impact of a hospital and lower its expenses. This method uses electricity and oxygen to replace many of the chemicals used in traditional washing processes. The electricity and oxygen are used to create ozone ($O_3$), which is dissolved into water (Ozone Laundry Handbook, [38]). The ozone must be made and dissolved into the water on site of the laundry

facility. Luckily, the system connects to existing water lines and requires non-invasive installation (Laundry Consulting, [37]). This simple change will improve the laundry system's efficiency and lower it's environmental and financial cost.

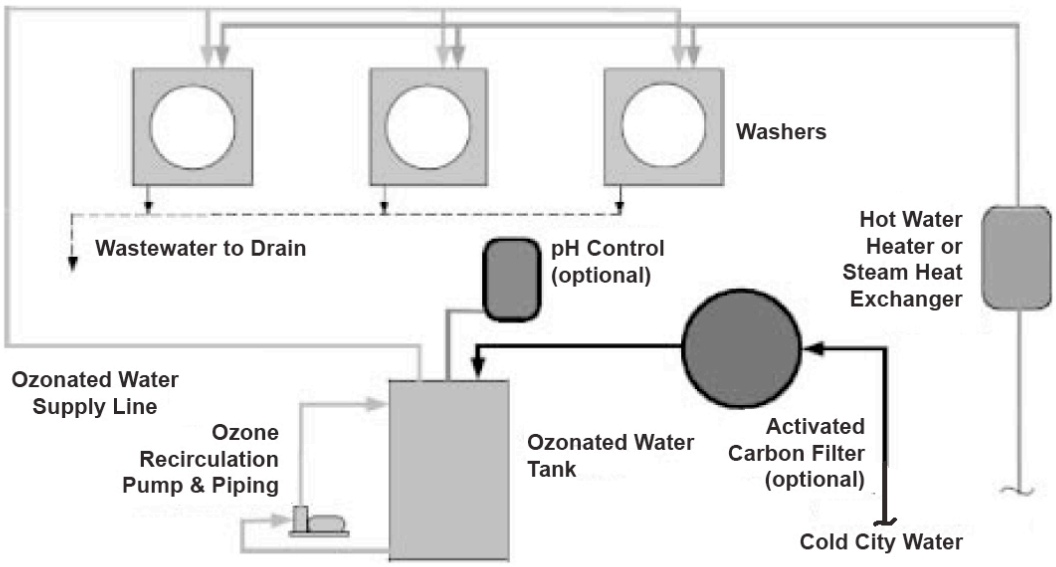


**Figure 10- A mechanical schematic of an ozone laundry system. Cold public water is circulated through an ozonated tank and pumped to the washers where it combines with hot water.**

Ozone is a powerful oxidizer that eliminates biological pathogens and other contaminants (See Table 12). Even strong, drug-resistant pathogens such as MRSA can be killed with ozone.

**Table 12- Oxidizing Agent vs. Oxidizing Potential**

| Oxidizing Agent | Oxidizing Potential |
|---|---|
| Fluorine | 3.06 |
| Hydroxyl Free Radicals | 2.80 |
| Atomic Oxygen | 2.42 |
| Ozone | 2.07 |
| Permanagenate | 1.67 |
| Hypochorous Acid | 1.59 |
| Chlorine | 1.36 |
| Molecular Oxygen | 1.23 |
| Bromine | 1.09 |
| Hypochlorite | .094 |

### 3.3.2 Analysis

Furthermore, unlike the chemical disinfects used in typical laundering, microorganisms cannot form a resistance to ozone. Ozone has the ability to blast through the cell wall of microorganisms, killing them instantly. A high pH level is desirable for the wash. In order to achieve high pH levels in the wash, OH molecules (Hydroxyl Radicals) must be created. Ozone uses a very small amount of alkali to produce these OH molecules compared to normal washing methods that require large amounts of alkali. Ozone also works as a water softener, reducing chemical demand and improving chemical performance, as the water's tendency to bead rather than penetrate the fabric is overcome (Ozone Laundry Handbook, [38]). This provides better quality results than typical chemical heavy washes, which damages fabrics by swelling the material to increase water retention. Linens cleaned by ozone will feel and smell brand new, and increase longevity over linens washed traditionally. The Environmental Protection Agency (EPA) recognizes ozone as the safest disinfectant, eliminating Clostridium difficile spores achieving high levels of Cryptosporidium and Giardia inactivation (Ozone Laundry Handbook, [38]). Table 13 highlights other levels of inactivation achieved using ozone.

**Table 13- Ozone High Log Inactivation Levels**

| **Ozone Level (ppm)** | **Contact Time** | **Bacteria Species** | **Percent Removal** |
|---|---|---|---|
| 0.009 | <1 min | E. Coli | 99.99% |
| 0.099 | <1 min | Staphylococcus sp. | 99.99% |
| 0.099 | <1 min | Pseudomonas Fluorescens | 99.99% |
| 0.21 | 5 min | Legionella pneumophila | 99% |
| Ozone Level (ppm) | Contact Time | Virus Species | Percent Removal |
| <0.8 | 5 min | Poliovirus 2 | 99.9% |
| 1.7 | 5 min | Coxsackie Virus B3 | 99.999% |

Most Ozone Laundry systems have an optimal dissolved ozone concentration of 1.5 to 3 ppm. This basically guarantees complete inactivation of all harmful pathogens present in linens.

Ozone laundry systems are not only effective but also efficient. The water temperature required to properly dissolve ozone into water is low, since heat accelerates the break up of unstable ozone molecules into diatomic oxygen and molecular oxygen. These systems reduce hot water usage by 90% and energy usage from the dryers by 50%. Dryer energy is reduced because fabrics washed with ozone require less drying time. Since ozone, unlike chemical wetting agents, does not cause fabrics to retain moisture, linens come out of the wash drier. A drier wash cycle will result in a shorter dry cycle for the linens. Ozone laundry systems can cut moisture retention by 75%, shortening the dryer cycle to less than 20 minutes (Laundry Consulting, [37]).


**Figure 11- Ozone washing machines reduce moisture content in the linens, therefore the dry time is less than using a standard dryer.**

Shorter washing and drying times also mean significant labor saving, and thus significant financial saving. Labor is one of the most expensive aspects of the laundry operation. The design of the ozone laundry facility also lends to its efficiency and saving labor costs. When measuring laundry efficiency, a high PPOH (pounds per operator per hour) value yields greater efficiency and lower labor costs. In order to achieve high PPOH values the laundry facility must be designed to allow employees to achieve their tasks with minimal movement. One way this is done, that also eliminates cross contaminants between dirty and clean linens, is pass thru dryers that open on both sides. Clean, wet linens go in one side and come out dry on the other (Laundry

Consulting, [37]). This allows the clean washing room to remain sealed, and free of airborne pathogens.

Ozone laundry systems eliminate the need for large amounts of chemicals in the washing process. The wastewater created from chemical based washing systems is high in biological oxygen demand (BOD) and chemical oxygen demand (COD) but low in dissolved oxygen (DO) (Ozone Laundry Handbook, [38]). Wastewater treatment plants are designed to lower BOD and COD while raising DO levels. Since laundry wastewater is so counter-productive to this, hospitals and other large-scale laundry facilities must 'buffer' their wastewater or be charged additional fees from the sewer company. Either option will have financial implications. On the other hand, using dissolved oxygen eliminates the need for chemicals and is full of Hydroxyl Radicals (OH Molecules), which are highly reactive and have an innate desire to bond (Ozone Laundry Handbook, [38]). Each bond will lower the BOD levels and any leftover OH molecules will increase DO levels. This creates wastewater that is actually productive at wastewater treatment, avoiding the need to 'buffer' or pay extra fees and fines for such awful wastewater.

Healthcare facilities can save large amounts of money by switching to ozone laundry system, while cutting down their environmental impact. They improve efficiency; use less water, less energy, less money and clean linens better than tradition cleaning practices. The healthcare system is an expensive operation, so optimizing laundry operation by utilizing ozone laundry systems allows for a reduction in labor costs, energy costs, and the environmental cost of running a hospital.

## 3.4 Biosensors

Detection and identification of pathogenic diseases is essential to prevent cross contamination in healthcare settings. Pathogen detection technology is advancing from conventional methods; many are able to present results in a timelier manner. Biosensors are efficient because they can identify diseases via rapid and sensitive detection. Medical personnel favor rapid detection so they can administer patient diagnosis in minutes. The device releases a biological agent that will transduce the recognition of a pathogen into a signal. This technological advancement could further prevent cross contamination and help raise awareness of pathogen population in healthcare facilities. However, biosensing technology is not limited for healthcare pathogen. They work well in detecting agricultural pathogens infecting food and water supplies.

### 3.4.1 Background

There are several requirements a biosensor must fulfill in order to function at their optimum potential. First, they must be able to display a low detection limit while still being highly sensitive. Most bacteria multiply and accumulate at rapidly, so even small quantities (<10 cells) of undetected bacteria can be harmful (Heo, J. et al [39]). Second, analysis time should be rapid so medical personnel can immediately treat infected patients. Third, biosensors must be able to detect and identify multiple strains of pathogenic disease at once. Simultaneous identification yields better data. Lastly, portability and ease-of-use are important factors for the design of the device.

Many biosensors are designed to detect pathogens, but not identify the strain. Many benign organisms in the air would be undetected. Thus, identifying the organism is critical for improving contamination prevention. This operation is known as detect-to-protect. Detect-to-protect is incredibly useful for medical personnel to be able to perform diagnostics in just minutes. Prior to rapid detect-to-protect sensing, it would take days for sample results to return from testing facilities (Petrovick, M. S., et al [40]).

One breakthrough technology that has been developed is CANARY. CANARY (Cellular Analysis and Notification and Antigen Risks and Yields) is based on genetically engineered B cells. B cells will bind to pathogens and recognize them to help the immune system fight an infection (Petrovick, M. S., et al [40]). B cells are extremely effective and are known as the fastest pathogen, having an inherent response of less than one second. The developers of CANARY genetically engineered B cells to emit photons once the cells bind with the target pathogen. When the cell antibodies bind to the bio-agent, a biochemical reaction is triggered that generates light emissions from aequorin. A photodetector will measure the luminescence of the light to generate results. In less than three minutes, CANARY technology can detect <50 colony-forming units of pathogens, out competing conventional biosensing methods that would take several days to generate results (Petrovick, M. S., et al [40]). Figure 12 represents how CANARY detects and concentrates bio-agents far quicker than existing bio-aerosol detection.

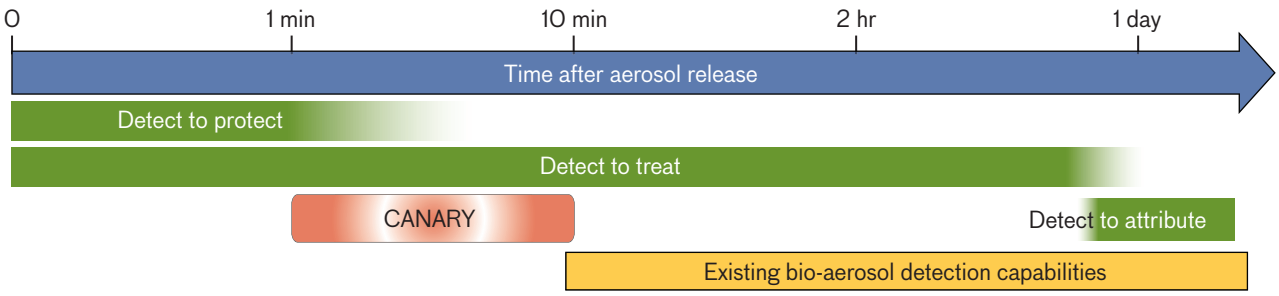


**Figure 12- Comparison of CANARY and existing bio-aerosol detection capabilities. CANARY is faster and more sensitive, which benefits applications like medical diagnostics.**

Scientists at MIT Lincoln Lab developed a biosensor that uses CANARY technology. The core of PANTHER (Pathogen Notification for Threatening Environmental Releases) is comprised of plastic disks that contain 16 chambers each. The chambers are pre-loaded with B cells so the device can administer 16 simultaneous tests for up to 48 bio-agents (Petrovick, M. S., et al [40]). The first PANTHER sensor developed was a portable device known as CUB (Compact Unit Biosensor). CUB is approximately 1 $ft^3$ and weighs 37 lb., which makes it accommodating.

### 3.4.2 Analysis

Biosensor technology is breakthrough in the detection and identification of pathogens. However, there are some implications for incorporating them in an ambulance. First is the price. The CUB costs approximately $20,000 to manufacture, which would be tremendously expensive to implement in many ambulances. The detection capability of biosensors is limited, and the elaborate equipment requires extensive preparation before operation. This makes it difficult for

EMTs to properly use it in an ambulance while on call. Modern biosensors are more feasible in a hospital setting rather than an ambulance.

## 3.5 Electrostatic Spray Cleaning

Medical and EMS personnel are open to seek improvements in ambulance cleaning procedures. One innovative washing technology being used for ambulance cleaning is electrostatic spray systems. Studies have shown that electrostatic sprayers are more effective in targeting the source than conventional sprayers (Electrostatic Spraying Systems, [41]). The compatible detergents and cleaning products used with electrostatic spray cleaners have been proven to kill microorganisms like MRSA and E. coli (Electrostatic Spraying Systems, [41]). Electrostatic sprayers will allow for a more precise cleaning system for ambulance cabins. Electrostatic spray technology is also very popular in agriculture, because the small droplets provide more plant coverage to destroy pests than conventional sprayers.

### 3.5.1 Background

Electrostatic sprayers function by combining electrostatics with fluid atomization. Simply put, pressurized air and water travel separately up the neck of the spray gun, until immediately before the tip of the nozzle, where they converge to form a mist of spray droplets. These droplets typically range in size from 30 to 60 microns in diameter (Electrostatic Spraying Systems, [41]). An electrode at the nozzle end applies electric charges to the spray droplets. The charge administered to the droplets can attract to the charges from the targeted surface. That force between the charges draws in the spray droplets to the target surface at 75 times the force of gravity (ref). This phenomenon of physics can be explained through Coulomb's law.

Coulomb's law is a law of physics that describes the interaction between electric charged particles (Coulomb, M., [42]). It is a principle law for the study of electrostatics. According to Coulomb's law, *the magnitude of the Electrostatics force of interaction between two point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distances between them* (Coulomb, M., [42]). When two like charges interact, the electrostatic force will repel the objects from each other. Whereas when two unlike charges interact, the electrostatic force will attract the objects to each other. This interaction can be described by equation 1:

$$F = \frac{Q_1 Q_2}{4\pi r^2 \varepsilon_0}$$

**(Eq. 1)**

Q1 and Q2 represent the two electric charges. ε0 is a constant representing the resistance around an electric field in free space (Mohr, P.J. et al. [43]) F is equal to the force, and r is the radius of the object.

The charge from electrostatic sprayers will either attract or repel spray droplets to the target. If a droplet repels charge from a section of the target source, it can redirect itself, opposing the force of gravity. The ability of the droplets to redirect into gravity creates what is known as the "wrap around" effect. The "wrap around" effect occurs when charged droplets scatter to oppositely charged and non-charged areas of the target surface. The spray can also

project droplets through turbulence and dense areas. Each droplet is approximately 900 times smaller than droplets from a conventional sprayer (Electrostatic Spraying Systems, [41]). Better spray coverage will generate a better return on investment.

The spray process from the nozzle tip is referred to as atomization. How well the sprayer nozzle atomizes will affect how well the spray will cover the target surface. Examples of products that incorporate atomizing nozzles are spray paint cans and perfume bottles. How they function is explained through fluid mechanics principles of the Venturi effect and Bernoulli's equation.

The Venturi effect states that the pressure of a fluid decreases as the area of a pipe decreases. While the pressure decreases, the velocity will increase. The velocity must increase through a pipe constriction in order to fulfill the principle of continuity of fluid dynamics. In other words, the rate the fluid enters the system must equal the rate of the fluid as it exits the system. This can be described through equation 2 for volumetric flow rate:

$$\boldsymbol{Q = v \cdot A}$$

**(Eq. 2)**

Q is the volumetric flow rate. A is the area of the pipe and v is the velocity. For example: the flow rate of water through a pipe is set at 10 cubic feet per second. The area of the pipe is 1 square foot. The velocity of the water would be 10 feet per second. If the pipe tapers to an area of 0.5 square feet, the exiting velocity would then be 20 feet per second.

For many applications, the volumetric flow rate cannot be set. Rather, the volumetric flow rate must be calculated. In order to do such, Bernoulli's equation must be applied. Bernoulli's equation is the basis of the Venturi effect. Bernoulli's equations describes that an

increase in speed of a fluid will occur simultaneously with pressure decrease. The pressure drop is represented in equation 3:

$$p_1 - p_2 = \frac{\rho}{2}(v_2^2 - v_1^2)$$

**(Eq. 3)**

Figures 13 and 14 are represented of this. $p_1$ and $p_2$ represent the pressure in sections 1 and 2. $v_1$ represents the speed of the fluid through the larger diameter section (section 1); $v_2$ represents the speed of the fluid through the smaller diameter section (section 2), and ρ represents the density of the fluid. Density is assumed to be constant for incompressible flow. Thus, flow rate is represented in equation 4 as:

$$Q = A_1\sqrt{\frac{2}{\rho}\cdot\frac{(p_1 - p_2)}{(\frac{A_1}{A_2})^2 - 1}} = A_2\sqrt{\frac{2}{\rho}\cdot\frac{(p_1 - p_2)}{1 - (\frac{A_2}{A_1})^2}}$$

**(Eq. 4)**

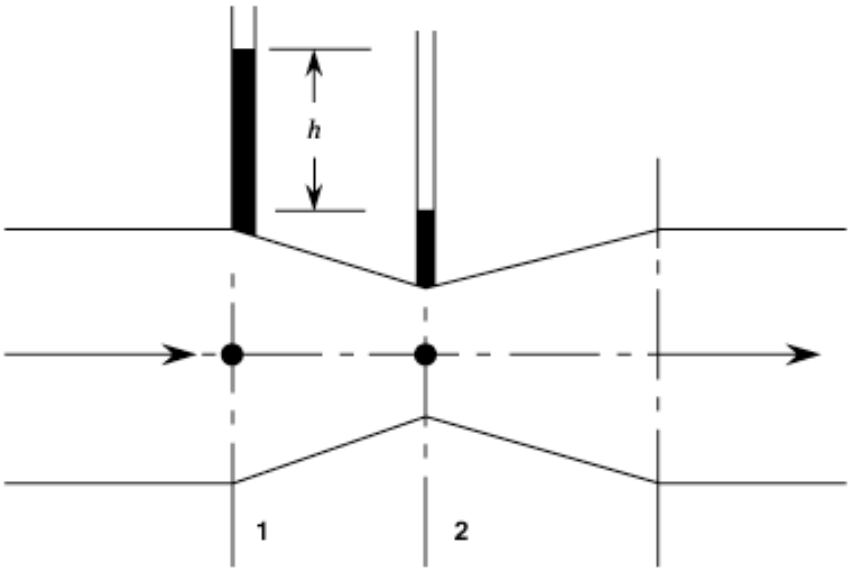


**Figure 13- Measuring tube representing pressure drop through a pipe constriction. The liquid level of the tube in section 2 is lower than the liquid level at section 1 since fluid pressure in the pipe decreases with the decrease in pipe diameter.**

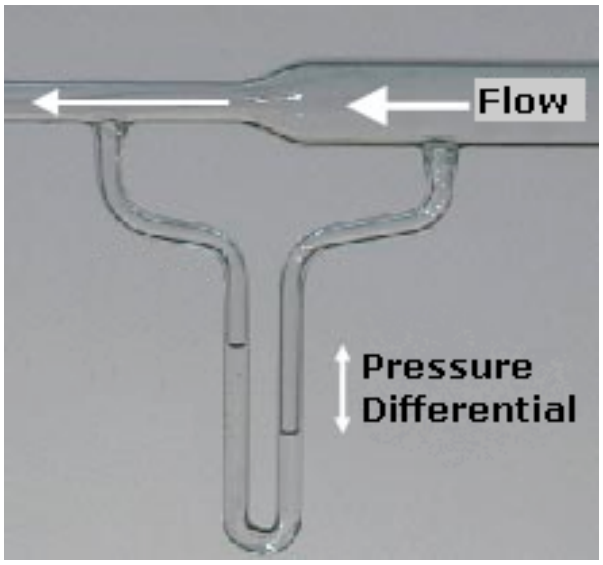


**Figure 14- Venturi meter representing pressure differential. The height of the fluid on the manometer's left side is pushed up the tube via Venturi effect.**

In the case of an atomizer nozzle, the decrease in pressure will draw the fluid level up from the reservoir until it meets the gas flow. For electrostatic sprayers, the liquid and gas flow meet at the nozzle tip, creating a misting spray. The Venturi effect does not only apply to atomizers. Carburetors in an internal combustion engine will use the Venturi effect to draw gasoline into the air intake.

### 3.5.2 Product Details

Electrostatic sprayers exhibit many benefits over traditional spray cleaners. First, electrostatic sprayers generally produce less chemical waste than conventional sprayers. Electrostatic Spraying Systems (ESS) is one of the most recognized manufacturers of electrostatic sprayers. Four major universities conducted tests comparing ESS with conventional sprayers on plants. The studies concluded that ESS produced 300% better spray coverage on hidden spots and dense clusters of plants (Electrostatic Spraying Systems, [41]). It was determined that only approximately 20% of spray from conventional sprayers covered the plant, 3% of which covered the underside, with 60% of the chemical cleaning solution being wasted into the ground (Electrostatic Spraying Systems, [41]). The reduction in chemical waste of ESS creates positive environmental benefits. ESS also uses low toxic chemicals as cleaning agents because of their less adverse health affects.

ESS makes electrostatic sprayers for both agricultural and industrial purposes. ESS is regarded as the leading producer of electrostatic sprayers in the world. In 2008, the EMS Expo awarded ESS with the Top Innovation Award (Prevent-Staph, [42]). Scott Cravens, publisher of EMS Magazine, said this about the award: “The EMS EXPO 2008 Top Innovation Awards are

designed to recognize innovations in products and services for the pre-hospital market (Prevent-Staph, [42])." This award is distinguishing, on the fact that it helps mitigate cross-contamination from ambulances to hospitals. Most sprayers made by ESS are compatible with multiple cleaning products like sanitizers and pesticides. ESS manufactures a line of small and compact sprayers that are portable for EMS personnel to use to clean ambulance cabins. The team researched different models of ESS cleaners that would be most practical for an ambulance. The "SC" line of ESS cleaners is deemed to be the most feasible option for ambulance cleaning.

The "SC" line of ESS is an award-winning device that performs well in ambulance cleaning. The SC-1 was the model represented for the EMS Expo award.

**Figure 15- ESS SC-1 Spray System. This device was the winner of the Top Innovation Award at the 2008 EMS Expo.**

Since there may be cracks and crevasses in the ambulance cabin, a cleaner must be able to penetrate into the cracks to yield the spread of microorganisms. While most ambulance manufacturers apply laminates to the patient cabin, abrasions on the surface can still occur. A cleaner like the SC-1 works well for penetrating into abrasions, thus decreasing the likelihood of acquiring disease. The SC-1 exhibits other good qualities in making it practical for ambulance use. It does not require an external air supply and comes in a durable case with wheels and retracting handle. Similar products made by ESS are the SC-EB and the SC-ET (as shown in Figures 16 and 17).


**Figure 16- ESS SC-EB Spray System**

**Figure 17- ESS SC-ET Spray System**

All three products have similar technical specifications. The dimensions of each are almost identical. One major downfall of the SC-EB compared with the other two is the smaller tank capacity. Instead of using the approximate one-gallon tank, two Nalgene bottles (measured at 1 L) are used for liquid storage. However, it does have the advantage of including a longer hose than the other two models. Other technical specifications can be seen in Table 14.

**Table 14- Technical Specifications of Compact ESS Devices**

| | **SC-1** | **SC-EB** | **SC-ET** |
|---|---|---|---|
| Tank | 1 gal. (3.8 L) | (2) 1 L bottles | 1.25 gal. (4.7 L) |
| Size | 22"H x 12"W x 15"D (56 cm x 30 cm x 38 cm) | 22"H x 16"W x 10"D (56 cm x 41 cm x 25 cm) | 22"H x 16"W x 10"D (56 cm x 41 cm x 25 cm) |
| Hose | 6 ft. (2 m) | 30 ft. (9.1 m) | 6-15 ft. (1.8-4.6 m) |
| Electrical Cord | 8 ft. (2.4 m) | 10 ft. (3 m) | 10 ft. (3 m) |
| Weight (full) | 40 lbs. (18.1 kg) | 48 lbs. (22 kg) | 43 lbs. (empty) |
| Flow Rate | 1 gal/hr (3.8 L/hr) | 1 gal/hr (3.8 L/hr) | 1 gal/hr (3.8 L/hr) |
| Drop Size | 40 micron VMD | 40 micron VMD | 40 micron VMD |
| Spray Range | Up to 8 ft. (2.4 m) | Up to 8 ft. (2.4 m) | Up to 8 ft. (2.4 m) |
| Required Electricity | 110V (220V max) | 110V (220V max) | 110V (220V max) |
| Chemical Compatibility | All | Most | All |

The group researched more electrostatic sprayers to help compare with the ESS models. Microbecide® manufactures a product similar to the "SC" line of ESS. The TC-320 (as shown in Figure 18) is a compact sprayer with as much versatility as sprayers made by ESS.

**Figure 18- Microbecide® TC-320 Electrostatic Spray Cleaner**

It is easy to clean and will not clog. The liquid line on the spray gun just needs to be disconnected from the container with solution and connected to the flush container. It works effectively in overhead application, so the operator does not need to worry about the coating not covering a ceiling. Its compact case includes two wheels and an extendable handle for easy mobility. All of the components of the spray gun are stainless steel to help protect from corrosion. The system is also covered with a one-year warranty. Table 15 lists more technical specifications of the TC-320.

**Table 15- Technical Specifications of TC-320 Sprayer**

| | **TC-320** |
|---|---|
| Tank | Unlimited |
| Size | 56 cm x 35 cm x 23 cm |
| Hose | 6 m (19.5 ft) |
| Air Compressor | 1.06 HP (800 W) |
| Weight (full) | 22 kg |
| Flow Rate | 20 mL/m - 14L/hr |
| Drop Size | 30-40 micron VMD |
| Spray Range | 3.2 m |
| Required Electricity | 220VAC/50Hz |

One unique feature of the TC-320 is the ability to adjust the flow rate of the spray. The flow can be adjusted from 20 mL per minute to 14 L per hour. The device has access to a flow gauge so the operator can monitor flow. Table 16 represents data developed from Microbecide® based on an operator spray speed of three seconds per square meter.

**Table 16- Flow Adjustment Data for TC-320 Sprayer**

| Gauge Setting | Area Coverage ($m^2$/L) | Required Time (min) | Flow Applied (mL/$m^2$) | Flow Sprayed (L/hr) |
|---|---|---|---|---|
| 240 | 83.33 | 4.17 | 12 | 14.4 |
| 230 | 86.96 | 4.35 | 11.5 | 13.8 |
| 220 | 90.91 | 4.55 | 11 | 13.2 |
| 210 | 95.24 | 4.76 | 10.5 | 12.6 |
| 200 | 100 | 5 | 10 | 12 |
| 190 | 105.26 | 5.26 | 9.5 | 11.4 |
| 180 | 111.11 | 5.56 | 9 | 10.8 |
| 170 | 117.65 | 5.88 | 8.5 | 10.2 |
| 160 | 125 | 6.25 | 8 | 9.6 |
| 150 | 133.33 | 6.67 | 7.5 | 9 |
| 140 | 142.86 | 7.14 | 7 | 8.4 |
| 130 | 153.85 | 7.69 | 6.5 | 7.8 |
| 120 | 166.67 | 8.33 | 6 | 7.2 |
| 110 | 181.82 | 9.09 | 5.5 | 6.6 |
| 100 | 200 | 10 | 5 | 6 |
| 90 | 222 | 11.11 | 4.5 | 5.4 |
| 80 | 250 | 12.5 | 4 | 4.8 |
| 70 | 285.71 | 14.29 | 3.5 | 4.2 |
| 60 | 333.33 | 16.67 | 3 | 3.6 |
| 50 | 400 | 20 | 2.5 | 3 |
| 40 | 500 | 25 | 2 | 2.4 |
| 30 | 666.667 | 33.33 | 1.5 | 1.8 |
| 20 | 1000 | 50 | 1 | 1.2 |

The operator should follow these guidelines in order to properly choose the flow rate for needed area coverage. Figure 19 demonstrates how much area coverage can be achieved at different flow spray rates.

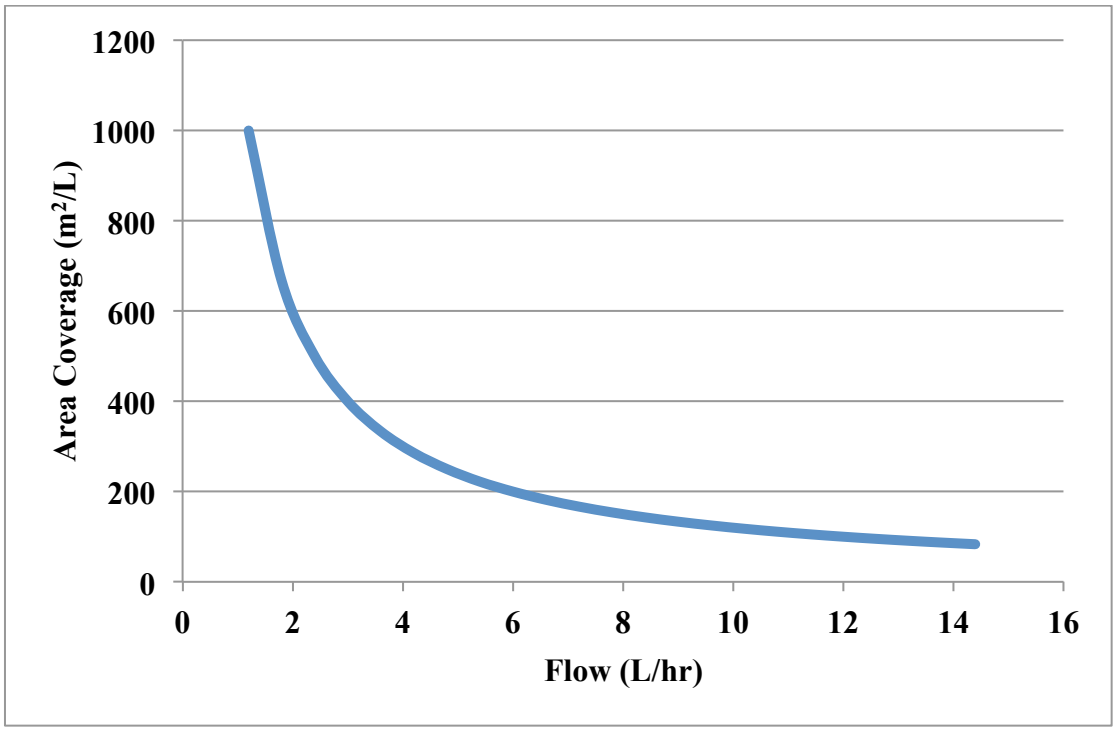


**Figure 19- Graphical Representation of Spray Flow vs. Area Coverage**

The TC-320, like most electrostatic sprayers, is relatively quiet. From Table 17, the average decibel rating for a Microbecide® sprayer in operation is 62, quieter than a standard vacuum cleaner. Starting price for a TC-320 is $7,000. Microbecide® also makes a hospital grade disinfectant. The Viropac disinfectant is proven to kill bacteria and viruses like H5N1 and H1N1. It's non-corrosive, non-bleaching and non-flammable, which is safer for the healthcare cleaning staff than using bleach solutions. Viropac is made to clean commonly contacted areas in the hospital, like door handles, computer keyboards, telephones and bed frames.

**Table 17- Noise Level Comparison of Microbecide® Sprayer to Various Noise Sources**

| Noise Source | dB Level |
|---|---|
| Breathing | 10 |
| Whisper, rustling leaves | 20 |
| Quiet rural area | 30 |
| Library, bird calls | 40 |
| Quiet suburb, conversation at home | 50 |
| Conversation in restaurant | 60 |
| Microbecide® sprayer in operation | 62 |
| Radio or TV-audio, vacuum cleaner | 70 |
| Average factory noise | 80 |
| Motorcycle (at 25 ft) | 90 |
| Jackhammer in operation | 100 |
| Live rock music | 110 |
| Thunderclap | 120 |
| Jet take-off (at 25 m) | 150 |

### 3.5.3 Analysis

After research and analysis of electrostatic spray cleaners, we have made conclusions for their implementation in ambulances. Larger models could even be used in hospitals. Using electrostatic spray cleaners would work well for ambulance cleaning protocol. A sprayer would work best for decontaminating the surface after is has been cleaned. A major benefit to electrostatic cleaners is the ability for the solution to dry quickly. Since there is not a drainage system installed in ambulances, all of the cleaning solution needs to be dried up. Electrostatic spray has the ability to dry quickly, which avoids having to use a device to dry the cleaner. If there is room available, a compact sprayer could be carried in the patient cabin. If not, the hospital or healthcare facility could store the cleaner. Studies have proven that electrostatic sprayers have better surface coverage than conventional sprayers. The group recommends electrostatic spray systems be used for surface decontamination in ambulances and hospitals.

# CHAPTER 4. CONCLUSION

## 4. Introduction

Advancements in the healthcare system have allowed for cleaner and safer hospitals and ambulances. However, just like the healthcare system, pathogens and contaminants advance as well. This means that current cleaning protocol and precautionary measure may not be adequate in protecting patients and healthcare providers from infectious disease. The major objective of our Interactive Qualifying Project is to research and recommend changes to the current precautionary standards as well the current cleaning procedure. The viability of these new engineering solutions must be evaluated taking into account cost, installation, and maintenance.

The IQP team began the project with extensive background research into common contaminants in the healthcare setting. These contaminants are split into two major groups; bloodborne pathogens and airborne pathogens. The source of these pathogens, their mode of transmission, and diseases they help spread were all researched to develop a better understanding of the scope of the contamination problem. We also investigated how hospitals and ambulances are cleaned and what types of substances are used in the process. Using this data, research was done to find available products that could benefit in the removal of contaminants.

In order to enhance the procedures and protocol in the healthcare system, the current standards were investigated. Our team visited the Worcester Ambulance Depot and spoke to healthcare professionals to gain their first hand insight into current limitations on decontamination. It was revealed that cleaning in both ambulances and hospitals is a time-consuming and expensive task. No one universal standard procedure exists for cleaning in the healthcare system. This is due in part to the rapidly changing healthcare environment as well as

time constraints and other factors. Project goals were then decided and a study of cheap, efficient, and effective methods of cleaning was conducted.

Five different products were researched: Air filters, biosensors, ozone laundry systems, electrostatic sprayers, and zolatone. Many of these products already receive widespread usage. For example, HEPA air filters have received acclaim throughout the healthcare industry for their ability to reduce airborne pathogen levels. Zolatone is a surface coating that is very easy to clean because it is scratch resist and will not allow pathogens to evade decontamination. Many ambulance design companies, such as Braun, utilize this coating in all of their emergency vehicles. Other methods, like ozone laundry systems, not only provide cheaper and more effective cleaning but also are a much "greener" choice than conventional laundry. The push for "green" cleaning products is part of the healthcare systems goal to be more environmental friendly on all fronts.

Overall, the recommendations provided by our IQP team are believe to be significant improvements to the procedures currently in place. Integrating the products studied in this project into the methods of decontamination and prevention used by hospitals and ambulances would allow for faster, more effective, cheaper cleaning.

There were several limitations to this project, such as only having access to free journal articles. A few of the products researched make use of proprietary technology that is difficult to find information on. Most of the work done for this project is theoretical, actual testing of all the products listed and procedures discussed should be completed to truly understand their viability.

Future work on this project might involve resolving the limitations experienced by our IQP team. For example, actual testing of HEPA filters or other substances used in cleaning. Also, further work can be done on the "green" side of healthcare. Developing cleaning protocol that

not only provides safe levels of contaminants but also are environmentally friendly is a major issue that requires additional focus and more research.

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# APPENDICES

## Appendix A: MRSA infections in health care workers

| | Number of healthcare workers with MRSA | Number of healthcare workers tested | Prevalence of MRSA in healthcare workers |
|---|---|---|---|
| Location (hospital vs non-hospital) | | | |
| Hospital | 1404 | 25884 | 5.4% |
| Non-Hospital | 42 | 1236 | 3.4% |
| Locations within Hospital | | | |
| Intensive Care Unit | 154 | 3309 | 4.7% |
| General Ward | 128 | 2032 | 6.3% |
| Burn Unit | 38 | 1326 | 2.9% |
| Baseline prevalence of MRSA among patients | | | |
| Outbreaks of MRSA | 863 | 22289 | 3.9% |
| MRSA endemic | 389 | 4782 | 8.1% |
| MRSA spordaic | 98 | 2234 | 4.4% |
| Medical Specialty | | | |
| Medicine and medical subspecialties | 49 | 1200 | 4.1% |
| Surgery and surgical subspecialties | 74 | 1651 | 4.5% |
| Age Group (patients) | | | |
| Adults | 601 | 12888 | 4.7% |
| Geriatrics | 50 | 946 | 5.3% |
| Paediatrcs | 111 | 3187 | 3.5% |
| Type of healthcare worker | | | |
| Medical staff | 79 | 991 | 8.0% |
| Nursing staff | 186 | 2499 | 7.4% |
| MRSA Isolation Practices | | | |
| Contact precautions or gowns and gloves | 531 | 9429 | 5.6% |
| No precautions or gowns and loves | 373 | 11362 | 3.3% |
| Private room or cohorting of patients | | | |
| Private rooms or | 306 | 12576 | 2.4% |

| | | | |
|---|---|---|---|
| cohorting | | | |
| No private rooms or cohorting | 586 | 7586 | 7.7% |
| Geographic regions | | | |
| Northern Europe | 101 | 1920 | 5.3% |
| Western Europe | 291 | 10851 | 2.7% |
| Southern Europe | 151 | 3121 | 4.8% |
| Eastern Europe | 8 | 511 | 1.6% |
| North America | 328 | 7886 | 4.2% |
| South America | 13 | 201 | 6.5% |
| Africa | 105 | 678 | 15.5% |
| Middle East | 136 | 2233 | 6.1% |
| South and Central Asia | 17 | 513 | 3.35 |
| East Asia | 132 | 1005 | 13.1% |
| Australia, New Zealand | 196 | 2017 | 9.7% |
| Total | 1545 | 33318 | 4.6% |

## Appendix B: Methods of sterilization and disinfection.

| | | Sterilization | | Disinfection | |
|---|---|---|---|---|---|
| | | Critical | High-level semi-critical | Intermediate-level | Low-level (noncritical items; |
| **Object** | **Procedure** | **Exposure time** | **Procedure (exposure time 12-30 min at ≥20°C)[2,3]** | **Procedure (exposure time ≥ 1 m) [9]** | **Procedure (exposure time ≥ 1 m) [9]** |
| Smooth, hard Surface | A | MR | D | K | K |
| | B | MR | E | L5 | L |
| | C | MR | F | M | M |
| | D | 10 h at 20-25°C | H | N | N |
| | F | 6 h | I6 | | O |
| | G | 12 m at 50-56°C | J | | |
| | H | 3-8 h | | | |
| Rubber tubing and catheters | A | MR | D | | |
| | B | MR | E | | |
| | C | MR | F | | |
| | D | 10 h at 20-25°C | H | | |
| | F | 6 h | I[6] | | |
| | G | 12 m at 50-56°C | J | | |
| | H | 3-8 h | | | |
| Polyethylene tubing and catheters | A | MR | D | | |
| | B | MR | E | | |
| | C | MR | F | | |
| | D | 10 h at 20-25°C | H | | |
| | F | 6 h | I[6] | | |
| | G | 12 m at 50-56°C | J | | |
| | H | 3-8 h | | | |
| Lensed instruments | A | MR | D | | |
| | B | MR | E | | |
| | C | MR | F | | |
| | D | 10 h at 20-25°C | H | | |
| | F | 6 h | J | | |
| | G | 12 m at 50-56°C | | | |
| | H | 3-8 h | | | |

| | | | | | |
|---|---|---|---|---|---|
| Thermometers (oral and rectal) Hinged instruments | A | MR | D | | K[8] |
| | B | MR | E | | |
| | C | MR | F | | |
| | D | 10 h at 20-25°C | H | | |
| | F | 6 h | I[6] | | |
| | G | 12 m at 50-56°C | J | | |
| | H | 3-8 h | | | |

**A,** Heat sterilization, including steam or hot air (see manufacturer's recommendations, steam sterilization processing time from 3-30 minutes)
**B,** Ethylene oxide gas (see manufacturer's recommendations, generally 1-6 hours processing time plus aeration time of 8-12 hours at 50-60°C)
**C,** Hydrogen peroxide gas plasma (see manufacturer's recommendations for internal diameter and length restrictions, processing time between 45-72 minutes).
**D,** Glutaraldehyde-based formulations (>2% glutaraldehyde, caution should be exercised with all glutaraldehyde formulations when further in-use dilution is anticipated); glutaraldehyde (1.12%) and 1.93% phenol/phenate. One glutaraldehyde-based product has a high-level disinfection claim of 5 minutes at 35°C.
**E,** Ortho-phthalaldehyde (OPA) 0.55%
**F,** Hydrogen peroxide 7.5% (will corrode copper, zinc, and brass)
**G,** Peracetic acid, concentration variable but 0.2% or greater is sporicidal. Peracetic acid immersion system operates at 50-56°C.
**H,** Hydrogen peroxide (7.35%) and 0.23% peracetic acid; hydrogen peroxide 1% and peracetic acid 0.08% (will corrode metal instruments)
**I,** Wet pasteurization at 70°C for 30 minutes with detergent cleaning
**J,** Hypochlorite, single use chlorine generated on-site by electrolyzing saline containing >650-675 active free chlorine; (will corrode metal instruments)
**K,** Ethyl or isopropyl alcohol (70-90%)
**L,** Sodium hypochlorite (5.25-6.15% household bleach diluted 1:500 provides >100 ppm available chlorine)
**M,** Phenolic germicidal detergent solution (follow product label for use-dilution)
**N,** Iodophor germicidal detergent solution (follow product label for use-dilution)
**O,** Quaternary ammonium germicidal detergent solution (follow product label for use-dilution)
**MR,** Manufacturer's recommendations
**NA,** Not applicable

## Appendix C: ESS Product Information

# ESS Model SC-1

***For disinfecting and sanitizing public areas, interior-scapes, and retail areas***

- Compact, unobtrusive sprayer ideal for sanitizing medical facilities and public transportation
- Durable wheeled case with extendable handle
- MaxCharge™ electrostatic spray gun
- Self-contained – does not require an external air supply
- Removable internal tank holds enough mix for 1 hour of spraying
- Quiet operation
- Runs on 110 volts
- Compatible with all conventional chemicals and fungicides

**Technical Specifications**

| | |
|---|---|
| Tank | 1 gal. (3.8 l.) |
| Size | 22"H × 12"W × 15"D (56 cm. × 30 cm. × 38 cm.) |
| Hose | 6 ft. (2 m.) |
| Electrical cord | 8 ft. (2.4 m.) |
| Weight (full) | 40 lbs. (18.1 kg.) |
| Flow Rate | 1gal./hr. (3.8 l./hr.) |
| Drop Size | 40 micron VMD |
| Spray Range | Up to 8 ft. (2.4 m.) |


**ELECTROSTATIC SPRAYING SYSTEMS, INC.**

62 Morrison St. · Watkinsville, GA 30677-2749
Office: 706-769-0025 · Toll-Free: 800-213-0518 · Fax: 706-769-8072
www.maxcharge.com · www.electrostaticspraying.com

## *Disinfection Sprayer*

# SC-EB

***Self-contained sprayer perfect for disinfection and sanitization applications***

- Compact, unobtrusive sprayer ideal for light-duty quick applications
- Discreet polyresin case has wheels and extendable handle for easy transport
- Includes one MaxCharge™ electrostatic spraygun
- Two one-liter bottles for easy spot spraying
- Compatible with most conventional chemicals

## Technical Specifications

| | |
|---|---|
| Nozzles | 1 |
| External air supply required | No |
| Electricity required | 110v |
| Dual Nalgene bottles | 1 Liter (1000 ml) each |
| Size | 22"H × 16"W × 10"D (56 cm. × 41 cm. × 25 cm.) |
| Hose | 30 ft. (9.1 m.) standard |
| Electrical cord | 10 ft. (3 m.) |
| Weight (full) | 48 lbs. (22 kg.) |
| Flow Rate | 1gal./hr. (3.8 L./hr.) |
| Drop Size | 40 micron VMD |
| Spray Range | Up to 8 ft. (2.4 m.) |
| Options | up to 100 ft. (30.5 m.) of hose (above standard will not fit inside case) |

Electrostatic Spraying Systems manufactures sprayers utilizing its patented MaxCharge™ technology. For more details please visit our website, **www.maxcharge.com**, or contact a representative at **(706)769-0025**.

**Call today for the best possible deal on a SC-EB sprayer for your operation.**

***Electrostatic Means Better Spray Coverage***


**Electrostatic Spraying Systems**

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Toll-Free: 800-213-0518 · Fax: 706-769-8072
www.maxcharge.com

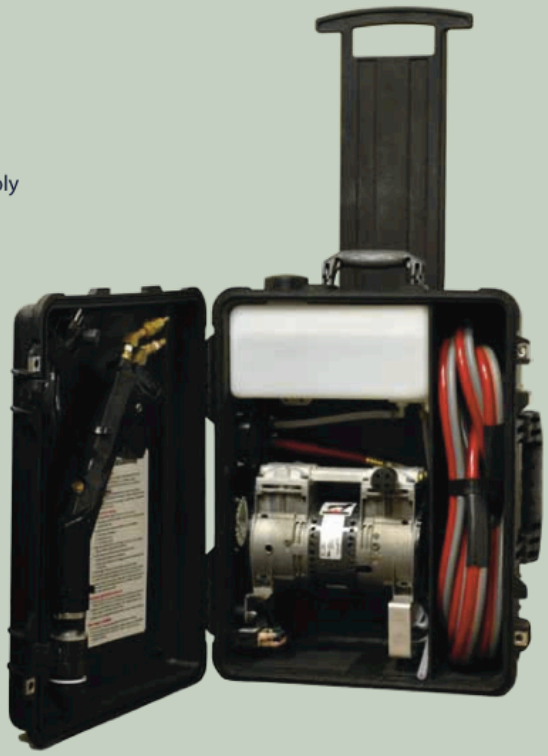

REV_MAR_2011

*Disinfection Sprayer*

# SC-ET

***For disinfecting and sanitizing public areas, interior-scapes, and retail areas***

- Compact, unobtrusive sprayer ideal for light-duty quick applications
- Durable wheeled case with extendable handle
- Includes one MaxCharge™ Electrostatic Spraygun
- Self contained, does not require an external air supply
- Internal tank holds enough mix for 1 hour
- Runs on 110volts (60hz)
- Compatible with most conventional chemicals
- Quiet operation
- Non-removable tank with drain hose and valve



## Technical Specifications

| | |
|---|---|
| Tank | 1¼ gal. (4.7 L.) |
| Size | 22"H × 16"W × 10"D (56 cm. × 41 cm. × 25 cm.) |
| Hose | 6 ft. or 15 ft. (1.8 m. or 4.6 m.) |
| Flow Rate | 1gal./hr. (3.8 L./hr.) |
| Weight (full) (empty) | 43 lbs. (22kg.) |
| Drop Size | 40 micron VMD |
| Spray Range | Up to 8 ft. (2.4 m.) |
| Electrical cord | 10 ft. (3 m.) |

Heavy-Duty option available with heat exchanger, perfect for extended use.

Electrostatic Spraying Systems manufactures sprayers utilizing its patented MaxCharge™ technology. For more details please visit our website, **www.maxcharge.com**, or contact a representative at **(706)769-0025**.

**Call today for the best possible deal on a SC-ET sprayer for your operation.**

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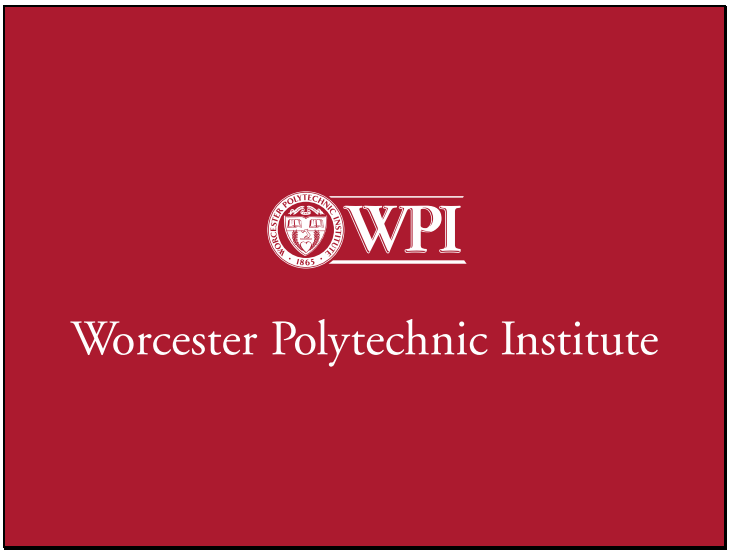
REV_MAR_2011

## Appendix D- Presentation




## Presentation Outline

- Motivation
- Project Statement
- Background Information
- Results and Discussion
- Recommendations
- Conclusion

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## Motivation

- Make advancements toward preventing nosocomial infections and other diseases
- Improve overall ambulance occupant safety and efficiency

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## Project Statement

- Research current cleaning protocols and contaminant complications in the EMS environment
- Suggest new methods of contaminant reduction (detection and cleaning)

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## Background Information

- Infections as result of hospital and ambulance treatment are the 4th leading cause of death in the United States
  - United States Centers for Disease Control and Prevention estimate 1.7 million patients receive healthcare associated infections each year
  - Approximately 99,000 die as a result in hospitals each year
- Forms of microbial life found in ambulances include:
  - Bacteria
  - Viruses
  - Fungi
- Not enough time to properly clean between calls
- Various fluids carried by patients from call to call

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## Background Information

- Annual direct medical cost due to healthcare associated infections (HAIs) ranges from $28.4-$33.8 billion in U.S. hospitals.
- Estimated per patient cost due to HAIs is $16,359 - $19,430
- Majority of these costs are device-related.

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## Documented Cases

| | Number of Infections | Estimated annual cost using consumer price index for inpatient hospital (billions) |
|---|---|---|
| Surgical Site Infection | 290,485 | $3.45 - $10.07 |
| Central Line Associated Bloodstream Infections | 92,011 | $0.67 - $2.68 |
| Ventilator Associated Pneumonia | 52,543 | $1.03 - $1.50 |
| Catheter Associated Urinary Tract Infection | 449,334 | $0.39 - $0.45 |
| Clostridium Difficile Associated Disease | 178,000 | $1.14 - $1.62 |
| Other | 674,752 | Varies |
| TOTAL | 1,062,373 | $28.4 - $33.8 |

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## Levels of Care

- Basic Life Support
  - 40-60 hours of training
  - Advanced first aid, CPR, Oxygen treatment, etc.
- Basic Emergency Medical Technician
  - 150 hours of training
  - Clear non-visualized airways, administer nitroglycerin
- Advanced Emergency Medical Technician
  - 250 hours of training
  - Cardiac monitoring, intravenous access techniques

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## Levels of Care

- Paramedic
  - 1500 hours of training
  - Experts in all basic and advanced life support skills
  - Advanced airway management, manual defibrillation operation, rapid sequence induction, CPAP, pleural decompression, etc.

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## Blood Borne Pathogens

- Blood Borne Pathogens
  - Improper/accidental needle punctures
  - Improperly cleaned tools and instruments
  - Bodily fluid transfer
  - Blood splatter
  - Failure of protective clothing and equipment
- Possible infections:
  - HIV/Aids, Hepatitis (B, C, D)

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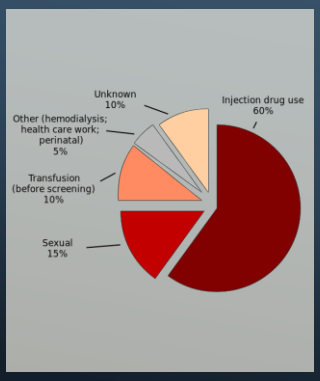
## Hepatitis C




Hepatitis C statistics:

- Can be transmitted via contact with infected blood
- Estimated 3.2 million cases in the US alone
- No current vaccine or standard cure
- Can remain infectious up to two days outside of the body at 37°
- A water and bleach solution can kill the virus outside of a host

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## Documented Cases- MRSA

| | Number of healthcare workers with MRSA | Number of healthcare workers tested | Prevalence of MRSA in healthcare workers |
|---|---|---|---|
| Hospital | 1404 | 25884 | 5.4% |
| Non-Hospital | 42 | 1236 | 3.4% |
| Total | 1446 | 27120 | 5.3% |

| | Number of healthcare workers with MRSA | Number of healthcare workers tested | Prevalence of MRSA in healthcare workers |
|---|---|---|---|
| Intensive Care Unit | 154 | 3309 | 4.7% |
| General Ward | 128 | 2032 | 6.3% |
| Burn Unit | 38 | 1326 | 2.9% |
| Total | 320 | 6667 | 4.8% |

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## Documented Cases- MRSA

| | Number of healthcare workers with MRSA | Number of healthcare workers tested | Prevalence of MRSA in healthcare workers |
|---|---|---|---|
| Northern Europe | 101 | 1920 | 5.3% |
| Western Europe | 291 | 10851 | 2.7% |
| Southern Europe | 151 | 3121 | 4.8% |
| Eastern Europe | 8 | 511 | 1.6% |
| North America | 328 | 7886 | 4.2% |
| South America | 13 | 201 | 6.5% |
| Africa | 105 | 678 | 15.5% |
| Middle East | 136 | 2233 | 6.1% |
| South and Central Asia | 17 | 513 | 3.3% |
| East Asia | 132 | 1005 | 13.1% |
| Australia, New Zealand | 196 | 2017 | 9.7% |
| Total | 1478 | 30936 | 4.8% |

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## Airborne Pathogens

- Airborne Pathogens
  - Coughing
  - Sneezing
  - Saliva and mucous splatter
  - Failure of protective clothing and equipment
- Possible infections:
  - Tuberculosis (TB), Severe Acute Respiratory Syndrome (SARS), Influenza, Meningitis

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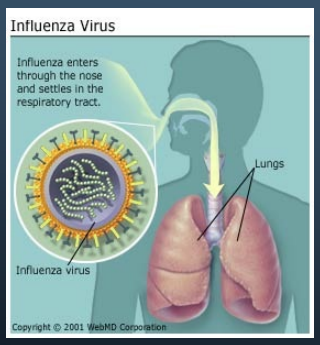
## Influenza




- Can be spread via direct transmission, inhalation of aerosols, hand to eye, hand to nose, or hand to mouth contact
- The virus can be controlled through good hygiene, avoiding contact between hands and mucous membranes, covering coughs and sneezes, and avoiding contact with infected individuals
- Lasts one to two weeks but can develop life threatening diseases or worsen chronic health problems

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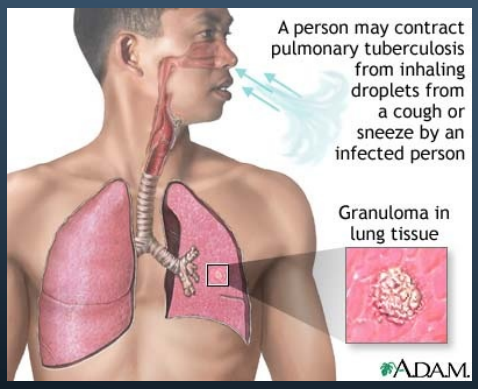
## Tuberculosis

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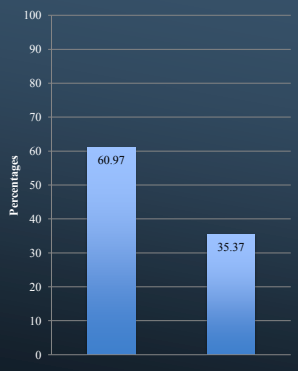
## Documented Cases- Tuberculosis




- Study conducted in 2002 analyzing tuberculosis levels in ambulances
- Bacterial colonies transported to areas that were previously sterile within the cabin
- Contamination found in entonox mask, steering wheel, stretcher surfaces, etc.

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## Definitions

- Cleaning: the removal of visible soil (e.g., organic and inorganic material) from objects and surfaces and normally is accomplished manually or mechanically using water with detergents or enzymatic products.
- Disinfection: process that eliminates many or all pathogenic microorganisms, except bacterial spores, or inanimate objects.
- Sterilization: process that destroys or eliminates all forms of microbial life, including bacterial spores.

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## Contamination Severity

- Critical: items that will enter vascular system or most tissues.
- (High level) Semi-Critical: items will cross mucous membranes and open wounds.
- (Intermediate level) Semi-Critical: some semi-critical items with some non-critical items.
- Non-Critical: items that will contact intact skin without penetration.

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## Disinfectants

| Object | Procedure | Exposure Time (min) |
|---|---|---|
| Smooth, hard surface | Ethyl or isopropyl alcohol | ≥1 |
| | Sodium hypochlorite | ≥1 |
| Thermometers and hinged instruments | Ethyl or isopropyl alcohol | ≥1 |

- Most common disinfectants: Ethyl or isopropyl alcohol, hypochlorites
- Hypochlorites most often used for spot disinfections, eg. blood spills
- Avoided in some cases because of corrosive nature
- Capable of disinfecting any surface contaminated with non-critical or semi-critical items

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## Sterilization

- Hot Steam Cleaning: effective, inexpensive, non-toxic
  - Pre-vacuum Systems: remove all air in sterilizing chamber prior to steam treatment, effective with porous media
  - Gravity Displacement Systems: typically run at 121° celsius, effective with non-porous media
- Ethylene oxide gas treatment

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## Gravity Displacement vs. Pre-vacuum

| Type of sterilizer | Item | Exposure time at 250°F (121°C) | Exposure time at 270°F (132°C) | Drying time |
|---|---|---|---|---|
| Gravity displacement | Wrapped instruments | 30 min | 15 min | 15-30 min |
| | Textile packs | 30 min | 25 min | 15 min |
| | Wrapped utensils | 30 min | 15 min | 15-30 min |
| Dynamic-air-removal (e.g., prevacuum) | Wrapped instruments | | 4 min | 20-30 min |
| | Textile packs | | 4 min | 5-20 min |
| | Wrapped utensils | | 4 min | 20 min |

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## Sterilization Procedure Parameters

| Object | Procedure | Exposure Time (min) | Temperature (°C) |
|---|---|---|---|
| Smooth, hard surface | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |
| Rubber tubing and catheters | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |
| Polyethylene tubing and catheters | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |
| Lensed instruments | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |
| Thermometers and hinged instruments | Heat Sterilization | 3-30 | 121-132 |
| | Ethylene oxide gas | 540-1080 | 50-60 |
| | Hypochlorite | 12-30 | ≥20 |

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# Recommendations

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## Ozone Laundry

| Oxidizing Agent | Oxidizing Potential |
|---|---|
| Fluorine | 3.06 |
| Hydroxyl Free Radicals | 2.80 |
| Atomic Oxygen | 2.42 |
| Ozone | 2.07 |
| Permanagenate | 1.67 |
| Hypochorous Acid | 1.59 |
| Chlorine | 1.36 |
| Molecular Oxygen | 1.23 |
| Bromine | 1.09 |
| Hypochlorite | .094 |

- Cleaning method using electricity and oxygen to replace traditional cleaners
- Ozone created through an electrical current and used eliminate pathogens and contaminants
- Micro-organisms cannot form any resistance

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## Ozone Laundry Assembly

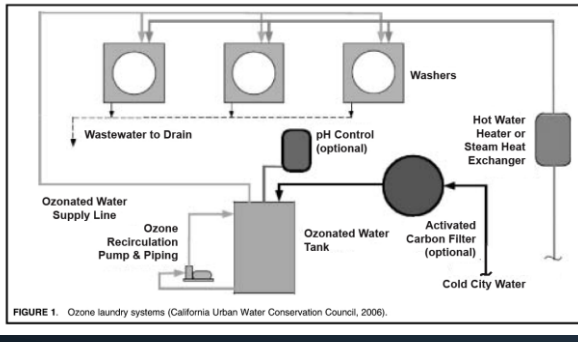


FIGURE 1. Ozone laundry systems (California Urban Water Conservation Council, 2006).

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## Effectiveness of Ozone

| Ozone Level (ppm) | Contact Time | Bacteria Species | Percent Removal |
|---|---|---|---|
| 0.009 | <1 min | E. Coli | 99.99% |
| 0.099 | <1 min | Staphylococcus sp. | 99.99% |
| 0.099 | <1 min | Pseudomonas Fluorescens | 99.99% |
| 0.21 | 5 min | Legionella pneumophila | 99% |
| Ozone Level (ppm) | Contact Time | Virus Species | Percent Removal |
| <0.8 | 5 min | Poliovirus 2 | 99.9% |
| 1.7 | 5 min | Coxsackie Virus B3 | 99.999% |

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## Electrostatic Spray Cleaners

- Deliver electrically charged spray droplets through high-speed air stream
- Charged droplets attract to surfaces (Coulombs Law), increasing coverage and decreasing need for chemicals
- Charge pulls droplets to surface at 75 times the force of gravity
- Penetrate into cracks and corners
- Air enters nozzle and atomizes exiting fluid (Venturi Effect)
- Commonly used with water-based chemicals, disinfectants, mold preventatives and sanitizers
- Help fight MRSA, E. coli, salmonella, and other viruses and bacterium

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## Sample Device- ESS


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## High Efficiency Particulate Air (HEPA)

- Designed by United States Department of Energy in 1940s
- Consist of web of fibers in random patterns
- Considered most effective filter in mechanical air cleaners by the EPA
- Capture particles through interception, impaction and diffusion
- Only filter particles, not gases
- Used in many ambulances

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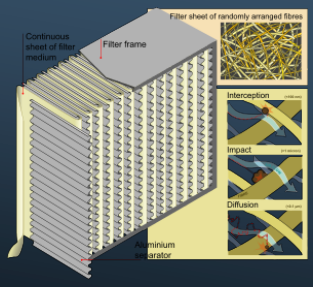
## HEPA Capture Mechanisms




- **Interception** - most commonly affects particles above .4 microns. The particle sticks to one of the filter's fibers after coming close enough to it.
- **Impaction** - most commonly affects particles above .4 microns. The particle is forced into contact with a fiber by the trajectory of the airstream in which it is traveling, and is embedded into it.
- **Diffusion** - most commonly affects particles below .1 microns. The arrangement of the fibers makes the particle collide with air or other gas molecules, and it is thrown off its course through the filter until it collides with a fiber.

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## Other Recommendations

- Biosensors
  - Transmits biological agents that transduce signals from pathogen recognition
- Non-abrasive nitrocellulos coatings (i.e. Zolatone)

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## Future Recommendations

- Evaluate cleaning steps and propose modifications
- Evaluate hand cleaners
- Evaluate cleaning chemicals for health and environmental hazards
- Propose more devices used for ambulance and hospital cleaning/pathogen detection

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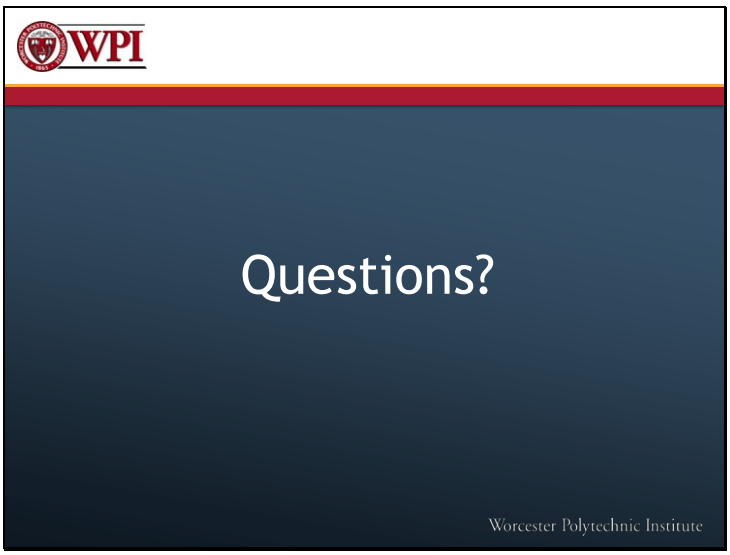
WPI
Questions?
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## Authorship

1 Coen

2
- 2.1 Chadwick
- 2.2
  - 2.21 Chadwick
  - 2.22 Gorgone
  - 2.23 Gorgone
- 2.3 Gorgone
- 2.4 Coen

3
- 3.1 Nowak
- 3.2 Nowak
- 3.3 Nowak
- 3.4 Coen
- 3.5 Coen

4 Nowak