The Use of Germicidal Light for the Sterilization of the U-bend of Hospital Sinks

A Technical Report submitted to the Department of Materials Science and Engineering

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On my honor as a University Student, I have neither given nor received
unauthorized aid on this assignment as defined by the Honor Guidelines
for Thesis-Related Assignments

Final Report: The Use of Germicidal Light for the Sterilization of the U-bend of Hospital Sinks

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2 Table of Contents

List of Figures

List of Tables

3. Executive Summary

Overall this project covers the design process involved in the development of our final design product. The steps for each section were written in real-time, this demonstrates how the group's ideas for solutions evolved and changed over time and accounts for the variations in ideas between group members. This diversity of thought in our group presents a varied approach to our challenge space and allows for us to brainstorm ideas that would not have been possible individually. The report effectively captures our thought process as we move through the design process before choosing the final UV-C light based purification system. It also covers planned changes and methods for testing the device.

This report covers the inception, planning, experimentation, and proposed implementation of our design project device. The paper starts with a background of the challenge space. This covers the issue of hospital acquired infections and various infection vectors in hospitals. It primarily focused on the different bacteria that cause the most hospital acquired infections and how they are transmitted. This analysis provided a clearer view of the difficulties faced by hospitals of what needed to be solved to decrease the number of infections. This analysis was helped by our interview with Dr. Guilford which presented the issue of bacterial infections caused by drug resistant bacteria growth in plumbing. Following the definition of the Challenge space the mission statement for the group's overarching goals with how to solve issues in the challenge space. The mission statement was particularly broad for this paper due to the fact that it was created before the group brainstormed solutions. As the project progressed this guided the solutions developed. The brainstorming solutions were heavily focused on solving the issues presented in the challenge space and aimed to address vectors of infection rather than aiming for the elimination of specific types of bacteria. There were a myriad of solutions developed, some which focused on the human element of infection others which focused on surface transmation and still others that focused on tool cleanliness. The solution that was chosen was to sterilize the plumbing of the sinks. The next section focuses on exploration of the design concept. After the exploration of the solution concept there is a design in detail section that indicates the specifics of the final product. The final section consists of individual reflections on the topics coupled with an analysis of how the project progressed and what potential measures can be taken to improve the solution concept.

4. Definition of Challenge Space

a.) Identifying the Challenge

Our team seeks to address the issue concerning Hospital Acquired Infections (HAIs) and their increasing prevalence within the healthcare system. Hospital Acquired Infections (HAIs) are defined to be infections that patients acquire during their hospital stay or within thirty days after their hospital visit as a result of bacterial transmission within the hospital setting.

Table 1: Breakdown of different bacteria and their impact

Bacteria	Percentage of Infections	Lethality (Nationally)
Clostridium Difficile	12.1	3%
Staphylococcus Aureus	10.7	16.7%
Klebsiella Pneumoniae	9.9	Blood stream infection: 47.9%
Escherichia Coli	9.3	General infection for US as a whole .082% With hemolytic uremic infection 3-5% Bloodstream Infections 3%

On this basis, it is essential to create and implement a solution that attempts to prevent, mitigate, and resolve these infections that occur unnecessarily. Within the realm of Hospital Acquired Infections (HAIs), it is necessary to consider the variety of factors that promote the spread of infections within different medical settings. Significant points of consideration include specific bacteria that cause infections, the methods of transmission of infections, and the current policies enacted as preventative measures of infections within these healthcare facilities. With regard to the exploration of these topics, an implementable solution will incorporate all necessary measures addressing bacteria, transmission methods, and policies that prevent the spread of Hospital Acquired Infections (HAIs) in order to improve the overall quality of life for patients and benefit all considered stakeholders.

Symptoms of these infections vary greatly depending on what type of infection it is and where the infection is located. *Clostridium Difficile* for example is primarily characterized by intestinal inflammation and diarrhea. *Staphylococcus Aureus* infections can cause bloodstream infections, and pneumonia when contracted by those with lung disease or equipped with a ventilator. *Klebsiella Pneumoniae* can cause pneumonia, bloodstream infections and UTIs. *Escherichia Coli* occupies a similar niche to *C. Diff* for intestinal infections, but can also cause UTIs and bloodstream infections.

b.) Root Causes of the Challenge

Consider the idea of a loved one undergoing a routine, minor, or even major surgery. Consider the nervousness your loved one feels, the apprehension your family feels, the uneasiness you feel. This situation is already financially, emotionally, and physically taxing in and of itself. Now, consider the idea of even just one more complication that further exacerbates this already draining experience: a Hospital Acquired Infection (HAI). Hospital Acquired Infections (HAIs) are prevalent throughout the world in a variety of healthcare settings that may lead to further complications for patients with lasting detrimental effects.

At the most basic level, the challenge of hospital or healthcare acquired infections (HAIs) are caused by pathogens. Many of these pathogens are invasive or opportunistic bacteria that are prevalent in a hospital environment. In this challenge space report we looked at four of the most prolific bacteria seen in HAIs: *Clostridium Difficile, Staphylococcus Aureus, Klebsiella Pneumonia, Eschira Coli.* These bacteria are some of the most common in hospital acquired diseases and can be life threatening to those infected. These bacteria proliferate throughout the hospital due to their resilience, rapid growth and adaptability. These can be spread through poor hand washing, contact with the surface or people with the disease, improper sanitation and cleaning of surfaces. According to the National Institute of Health's data on HAIs, "*C. difficile* (12.1%) is the leading cause followed by *Staphylococcus aureus* (10.7%), *Klebsiella* (9.9%) and *Escherichia coli* (9.3%)."

Hospital Acquired Infections (HAIs) are a pressing concern in the modern medical environment, and the wide-spread usage of antibiotics has led to bacteria adapting to be more antibiotic resistant. This has made infections more difficult to treat and more dangerous when contracted, so one of the main concerns is avoiding the spread of the disease in the first place.

c.) Credible Sources Proving Challenge

According to the Center for Disease Control (CDC), "Although significant progress has been made in preventing some healthcare-associated infection types, there is much more work to be done. On any given day, about one in 31 hospital patients has at least one healthcare-associated infection." The CDC further states that over 1.7 million patients annually across the United States of America admitted into hospitals while being treated for other health-related issues acquire infections within these healthcare settings, with over 98,000 of these Hospital Acquired Infection (HAI) cases resulting in an unfavorable patient outcome: death.

d.) Synthesize Knowledge Gained from Multiple Sources

Through the collection external research from a variety of sources and topic considerations, the main points of focus within our research include an exploration of pathogenic bacteria, methods of infection transmission, populations at risk, stakeholders affected, and policy implementation within medical facilities all with regard to Hospital Acquired Infections (HAIs). Among the list of pathogenic bacteria, C. Difficile is the most common bacteria found in hospital acquired infections, closely followed by Staph, Klebsiella and E. Coli. Further research suggests that individuals with already weakened immune systems are the most at risk to contract Hospital Acquired Infections (HAIs); this makes them more likely to be infected and more likely to experience increased severity of infections. While there are specific places within the hospital setting that the proliferation of infections is more likely to witness, such as operating rooms, emergency care rooms, and intensive care units, this is due to the population characteristics of the individuals being treated within these spaces with weakened immune systems as a result of their initial treatment. Based upon the most common methods of transmission of these infections within the chosen setting based on acute primary care hospital facilities, an implementable solution explores a variety of options for addressing the many compounding factors that have led to the proliferation of Hospital Acquired Infections (HAIs) in healthcare settings. Current policy practices rely on a disjointed relationship between responsibilities of patient care in which hospitals, physicians, and caretakers put the responsibility of safety on that of the patient rather than adjusting their practices in the face of widespread infection proliferation. Current implemented methods of prevention include sterilization of instruments, isolation of potentially infectious diseases, safe handwashing practices, proper equipment and dress, surface sanitation, and the implementation of antimicrobial surfaces as just some of the varied policies employed.

e.) Harms or Benefits Resulting from the Challenge

Potential benefits resulting from the challenge space present the possibility for a greater quality of life for all stakeholders involved. By preventing the proliferation of Hospital Acquired Infections (HAIs), benefits include decreased healthcare costs, shortened hospital stays, mitigated emotional damage for both patients and their families, fewer legal disputes between patients and medical entities, increased perception of safety, and fewer deaths as a result of preventable infections.

Potential harms resulting from the challenge space present the possibility for increased cost of solution implementation, resistance of implementatable policy or technology, non-standardization of solution implementation across all medical facilities, and the effectiveness and timeliness of implementation in preventing Hospital Acquired Infections (HAIs).

f.) Key Stakeholders

Possible stakeholders in the case of Hospital-Acquired Infections (HAIs) include patients, hospital workers, both governmental and private health based organizations, communities with possible connections to healthcare facilities, and insurance companies. We believe that the above listed groups are interested in our project and can contribute information about Hospital-Acquired Infections (HAIs) along with suggestions.

g.) Areas in Which, Multiple, Measurable Design Requirements can be Determined

Within the scope of this project challenge, it is necessary and informative to consider specific and measurable design requirements that include but are not limited to:

- The number of cases involving Hospital Acquired Infections (HAIs) on a national, statewide, and local scale
- The number of deaths resulting from Hospital Acquired Infections (HAIs) on a national, statewide, and local scale
- The cost incurred by patients and family members as a result of treatment for Hospital Acquired Infections (HAIs)
- Past, present, and future policy plans for the prevention and control of Hospital Acquired Infections (HAIs)
- The cost of implementation of a proposed solution in the prevention of Hospital Acquired Infections (HAIs)

External Research

Most Common Pathogenic Bacteria

Clostridium Difficile

Disease

Clostridium Difficile is one of the most common hospital acquired infections, it is a bacterial infection that infects the colon and can cause symptoms including diarrhea to life-threatening inflammation. Due to the fact that this bacterium forms a spore, it is very resistant to unfavorable environments and is resistant to disinfectants that do not contain bleach. Symptoms of a severe infection include diarrhea, abdominal cramping, rapid heart rate, fever, blood or pus in stool, nausea, dehydration, loss of appetite, weight loss, swollen abdomen, increased white blood cell count, severe intestinal inflammation, sepsis, enlargement of the colon, and kidney failure. (Mayo Clinic 2019)

Classification and Structure

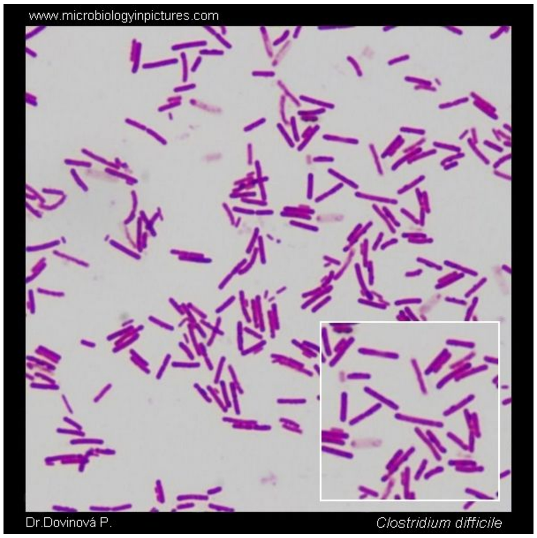
Clostridium difficile is a Gram-positive bacterium, it is an obligate anaerobic bacterium, meaning that it requires a lack of oxygen to survive, and is capable of forming endospores as a means of infection and surviving unfavorable conditions. This spore is essential in surviving oxygenated conditions which are toxic to the vegetative cell. This bacterium possesses two main toxins, enterotoxin TcdA and cytotoxin TcdB which cause damage to the epithelium and induce inflammatory responses (NIH 2015). It is primarily transmitted through improper sanitization after contact with spores stored in fecal material. This could be due to poor hand washing or improper sanitation of surfaces. One can become infected after these spores pass through the digestive tract. The spores formed by the bacterium are immune to the acidic conditions in the stomach and can persist anywhere from weeks to months and reactivate upon accessing their proper conditions

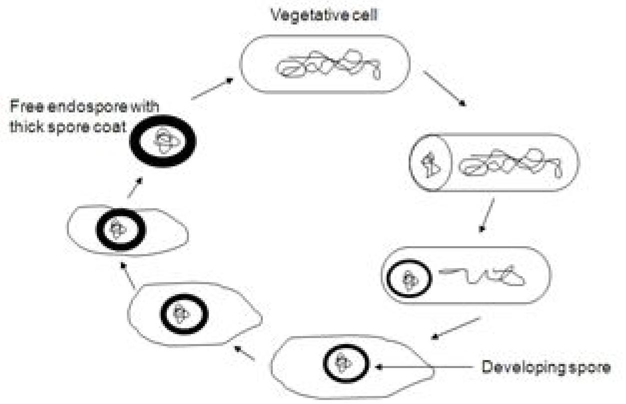
Populations at Risk

Most *C. Difficile* infections affect older adults in hospitals and those who have recently used antibiotics are particularly susceptible. This bacterium can gain a foothold in the intestines after the use of antibiotics to fight an infection, this kills some helpful intestinal bacteria and allows C. difficile to grow. Staying in a healthcare facility significantly increases the chance of infection and having a serious illness or recent medical procedure further increases the likelihood of infection. Having a previous C. difficile infection increases the likelihood of having later infections. Older people also have an increased chance of infection.

Statistics on *C. Difficile* Infections

There is a rising trend of infection in the United States. In 2015 the CDC found that it caused half a million infections in patients in a year and estimates that 15,000 deaths were caused by C. difficile infections.





Staphylococcus Aureus

Disease

Staphylococcus Aureus is a bacterium that was responsible for roughly 11% of hospital acquired infection in 2014 and has remained one of the leading causes of infection. Though normally harmless, Staph infections can be serious or fatal in health care settings. Some of the serious infections they can cause include sepsis when in the bloodstream, and pneumonia when contracted by those with lung disease or equipped with a ventilator. They can also lead to complications such as Endocarditis, or infection of the heart valves and Osteomyelitis which is a bone infection made possible by trauma or an infection already present in the bloodstream. Additionally, *S. Aureus* can cause toxic shock syndrome. The S. Aureus bacterium produces exotoxins including hemolysins, which destroys red blood cells, and leukotoxins, which specifically destroy white blood cells. Additionally, the combination of toxins secreted allow *S. Aureus* to avoid destruction by the host. There are several different Staph bacteria that are notable for their ability to cause infection; methicillin-resistant Staphylococcus aureus (MRSA), methicillin-susceptible Staphylococcus aureus (MSSA), vancomycin-intermediate

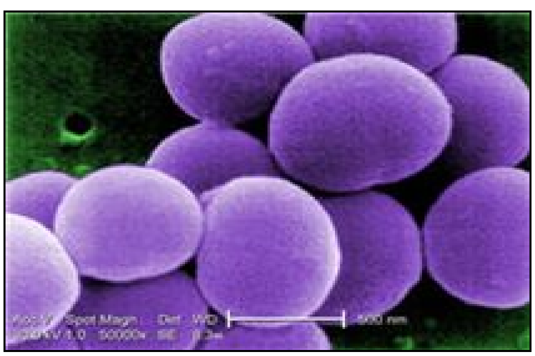
Staphylococcus aureus (VISA), and vancomycin-resistant Staphylococcus aureus (VRSA). Though all dangerous, the most notable is MRSA, due to its antibiotic resistance and prevalence as a disease-causing bacterium.

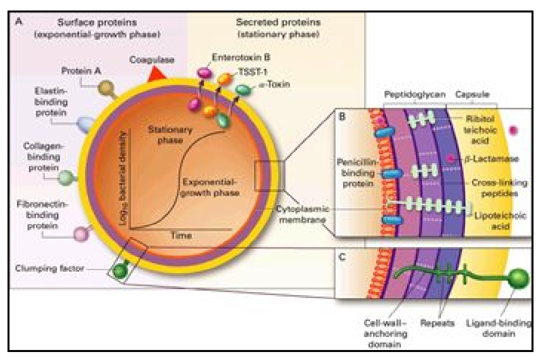
Populations at Risk

S. Aureus is a relatively common bacterium on the skin, and many people carry it, but do not develop infections. According to the CDC, "Studies show that about one in three (33%) people carry *S. aureus* bacteria in their nose, usually without any illness. About two in every 100 people carry MRSA. Although many people carry MRSA bacteria in their nose, most do not develop serious MRSA infections." However, there are several factors that can increase the likelihood of a staph infection. Uncovered wounds, sharing personal items, injection of drugs, and uncovered wounds can all lead to staph infections. Those who are staying in a hospital are at particular risk due to long stays, surgery, medical devices such as IVs, and potential exposure to people already carrying staph.

Classification and Structure

Staphylococcus Aureus is a gram-positive spherical bacterium, they notably occur in several different configurations including: single cells, pairs, short chains, and grape like clusters. This bacteria notably excretes harmful exotoxins, which causes cell death and is one of the leading disease-causing factors.





Statistics on Staph Infections

According to the CDC, more than 119,000 people suffered from bloodstream staph infections alone, and nearly 20,000 of those infected died. Between 2005 and 2012 MRSA infections in hospitals have decreased, on average 17% a year, but from 2012 to 2017 saw stalling reductions in MRSA and a 4% increase in MSSA. Staph infections are still a significant threat in healthcare settings and is a problem that is being continuously worked on in hospitals.

Escherichia coli

Disease

E. Coli infections vary in severity, and typically only last 5-7 days, but can be life threatening for those with weakened immune system. It is also mainly passed on as a foodborne illness (85%), but is a prevalent hospital acquired infection. This bacterium can grow in the lower intestines, they typically help with digestion, however there are several strands that cause severe infection when allowed to grow in the intestine. The *E. Coli* bacterium emits an exotoxin. Similar to the *C. Difficile*, it is transmitted fecal to oral route. However, *E. Coli* is able to live outside the host unlike *C. Difficile*. *E. Coli* can cause hemolytic-uremic syndrome, which can cause kidney failure. Urinary tract infections are one of the most common bacterial infections, and *E. Coli* can colonize the patient's urethra.

Classification and Structure

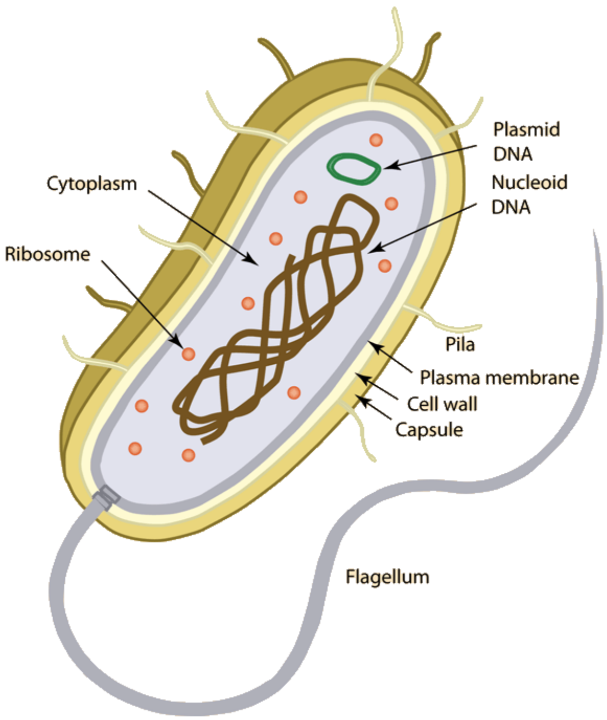
E. Coli is a rod-shaped bacterium that is notable for its simple cell structure that is notable for its rapid growth and relatively simplistic genome. *E coli* is a facultative anaerobe, and doubles approximately every two days inside a host, but dies after approximately 4 days in the outside environment. *E. coli* possesses a circular chromosome and can possess multiple smaller circular strands of DNA called plasmids. This bacterium is a gram negative which means that it has a thin layer of peptidoglycan on the outside of the bacteria. It is enveloped in the cytoplasmic membrane, peptidoglycan and outer membrane.

Population at Risk

E. Coli is one of the most common bacteria that cause urinary tract infections. This bacterium is a common bacterium in hospital acquired infections. The elderly population and children are particularly susceptible to this pathogenic bacteria.

Statistics on *E. Coli* Infections

It is important to note that 85% of *E coli* infections are foodborne. However, catheter based infections are one of the most common forms of hospital acquired infections. *E coli* has been found to be responsible for 90% of UTIs



Klebsiella Pneumoniae

Disease

Klebsiella is a prevalent bacterium that can cause pneumonia and bloodstream infections. It can spread through person-to-person contact. This disease can be spread in a hospital setting through ventilators or intravenous catheters or wounds. According to the CDC, patients can reduce the chance of infection by washing hands frequently and avoiding touching hospital surfaces. It is one of the second most frequent pathogen for UTIs and is notable for its increasing common prevalence as a drug resistant strain. The CDC recommends proper handwashing and contact precautions such as donning a gown and gloves before entering an affected patient's room, to prevent the spread of bacteria.

Classification and Structure

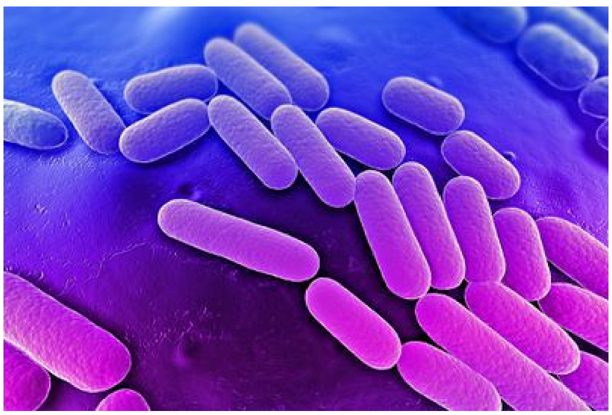
Klebsiella are a normal part of the human gut bacteria, but certain strains can cause infections. These bacteria can also become drug-resistant, which can make treating infections more difficult. *Klebsiella* is a rod-shaped, gram-negative bacterium similar to *E coli.* This bacterium is an opportunistic pathogen that mostly affects those with weakened immune systems.

Population at Risk

Patients who are under hospital care are the most at risk to contract a *klebsiella* disease. Those who have catheters, open wounds and ventilators are at particular risk from infection. As stated, before this bacterium is opportunistic, and is more likely to cause problems for those who already have health problems and healthy individuals have a very low risk of contracting it.

Statistics/Trends on *Klebsiella* Infection

In recent years more drug resistant strains of *Klebsiella pneumoniae* have become more prevalent.



Means of Transmission

There are various means in which a patient can come into contact with a hospital acquired infections. The infection can be transmitted via contact (direct or indirect), respiratory droplets, and airborne spread. Although contact-spread is the principal route of transmission for most infections, studies show that the other means of transmissions are still prevalent.

Contact Transmission

Although an infected health care worker can touch a patient and directly transmit a large number of microorganisms to the new host, the most frequent route of transmission, however, is indirect contact. The infected patient touches and contaminates an object, an instrument, or a surface. Subsequent contact between that item and another patient will be likely to contaminate the second individual who may then develop an infection. A study was conducted at the Volta Regional Hospital of Ghana to determine potential sources. Using a swab stick to swab taps, nurses' desks, main door handles, and door surfaces of lavatories and the various theatres of the hospital, it was then concluded the lavatory, tap, and writing desks recorded the highest pathogenic isolates. Thus, hand hygiene is critical to preventing health care associated infections, but adherence to guidelines is poor among healthcare workers. The Centers for Disease Control (CDC) guidelines suggest hand washing with antimicrobial soap between every patient contact and before and after performing invasive procedures. Healthcare workers in intensive care units have been reported as failing to wash their hands more than half of the recommended times, and even when performed, the procedure was inadequate. Hospital staff report several reasons for poor hand washing compliance such as inconvenient sink location, shortage of sinks, lack of time, lack of soap or paper towels, and forgetfulness.

Respiratory Droplets

Coughing, sneezing, talking, suctioning, and bronchoscopy can all generate fluid droplets that can travel through the air before hitting a surface. Respiratory droplets carry infectious pathogens and transmit infection when they travel directly from the respiratory tract of the infectious individual to susceptible mucosal surfaces of the recipient making it necessary to have facial protection. Examples of diseases where microorganisms can be spread by droplet transmission are pharyngitis, meningitis, and pneumonia.

Airborne Transmission

Airborne transmission is known to be the route of infection for diseases such as tuberculosis, aspergillosis, measles, and chickenpox. Airborne infections spread when bacteria or viruses travel on dust particles or small respiratory droplets that become aerosolized when an infected person sneezes or coughs. Healthy people can inhale the infectious droplets, or the droplets can land on their eyes, nose and mouth. Hospitals have special air handling and ventilation systems in some rooms to protect their patients.

Waterborne Transmission

Water, an overlooked source of waterborne pathogens, also causes infections in health-care facilities particularly to patients who are highly immunocompromised or have invasive devices. Contamination by waterborne pathogens in a hospital environment can occur because water temperatures are suitable for bacterial growth, and the complex structure of hospital water plumbing systems often leads to stagnation, corrosion, and biofilm formation. Potable water, sinks, faucet aerators, showers, tub immersion, toilets, dialysis water, ice and ice machines, water baths, flower vases, eyewash stations, and dental-unit water stations are some of the many water reservoirs that are linked to HAI outbreaks. Waterborne pathogens include Legionella, other Gram-negative bacilli, nontuberculous mycobacteria (NTM), fungi, protozoa, and viruses. Transmission of these pathogens from a water reservoir can occur by direct/indirect contact, ingestion of contaminated water, or inhalation of aerosols. According to the CDC, there are many design rules water systems should follow to reduce the colonization and multiplication of bacteria. Water should not be allowed to stagnate and should be circulated at temperatures below 20°C or above 60°C. When designing a sink, high flow over drains should be avoided. In addition, they should be placed far from critical patient areas and ideally the sinks should have hands-free faucets. Sinks and drains can become contaminated by pathogens that stick to pipes to form biofilms. As a result of the accumulation of various types of bacteria, drains can serve as sites where antibiotic resistant genes are transferred between bacterial species. A patient is exposed to these organisms when water splashes from the drain and can contaminate the skin. Despite attempts to reduce these pathogens in drains, there is still no clear solution to completely get rid of biofilms.

Stakeholders

Patients

Patients are the primary stakeholders for HAIs because they are targets of infections located in healthcare settings. Patients are more exposed to HAIs into ways; Intrinsic risk and extrinsic factors. Intrinsic risk factor comes from the patients internal health status including Patients that are immunocompromised and Patients with alteration to cellular immune function (10). As a result of weak immune system,patients can contract several infections. The second way patients can be a target for HAIs is through extrinsic risk factors that has to do with every procedure that require penetration into the patient's body parts. It includes insertion catheter and bloodstream devises. Invasive medical devices bypass the normal defense mechanism of the skin or mucous membranes and provide foci where pathogens can flourish, internally shielded from the patient's immune defenses (10). If ignored, invasive medical devices could transmit infections from one patient to another. In general, patients receiving treatment in locations like the Intensive Care Unit (ICU) are more likely to get involved in HAIs cycle.

Healthcare Workers and Governmental/Private Organizations

Infection Preventionists are people who work to reduce bacterial contamination in healthcare settings. They include doctors, nurses, public health workers, and epidemiologists. In addition, there are groups within this category including hospital board members, community spokesperson. From a leadership perspective, people who are at the management position of healthcare settings from policy creators to public health officials to budget committees all play an important role in changing the status of a health outcome. In addition, governmental organizations including the CDC (Center for Disease and Control) and the U.S Department of Labor can be considered as active participants by designing projects and implementing policies within the healthcare system.

Communities

These are community groups who represent patients and residents of the community. In other words, they are people with any connection to healthcare facilities and directly or indirectly get impacted by the actions of those facilities. When it comes to HAIs, the actions that could impact communities include infection breakouts throughout the hospital spreading out in the community and infection prevention methods by health facilities to list a few. Community groups engage in an investigative manner when they recognize that healthcare officials seem to ignore addressing important aspects that could risk the lives of patients.

UVA: ll of the figures below represent data presented with regard to the UVA Health System. Retrieved from https://uvahealth.com/about/quality-safety/central-line-associated-bloodstream-infections-clabsi

Figure 8: Central-Line Associated Bloodstream Infections - All Hospital Patients

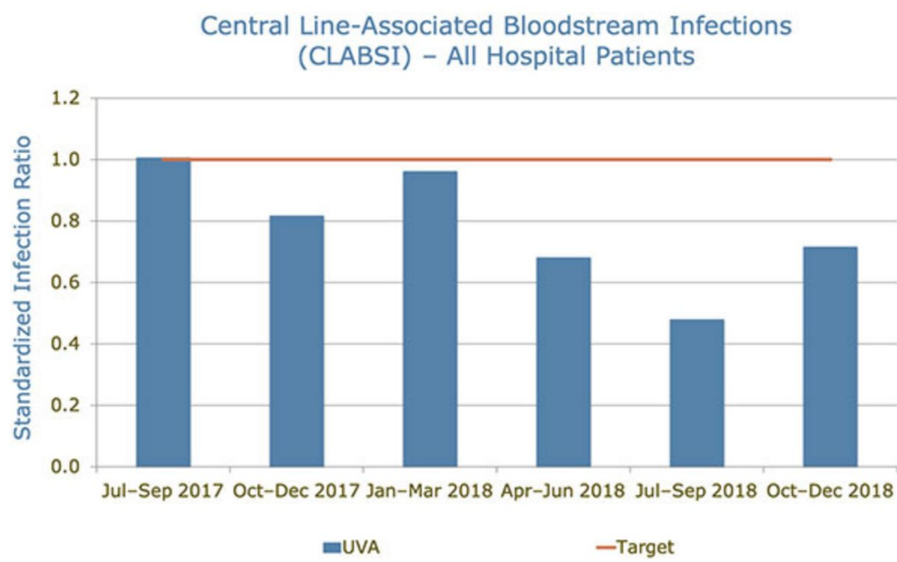


Figure 9: Central-Line Associated Bloodstream Infections - Adult Hospital Patients

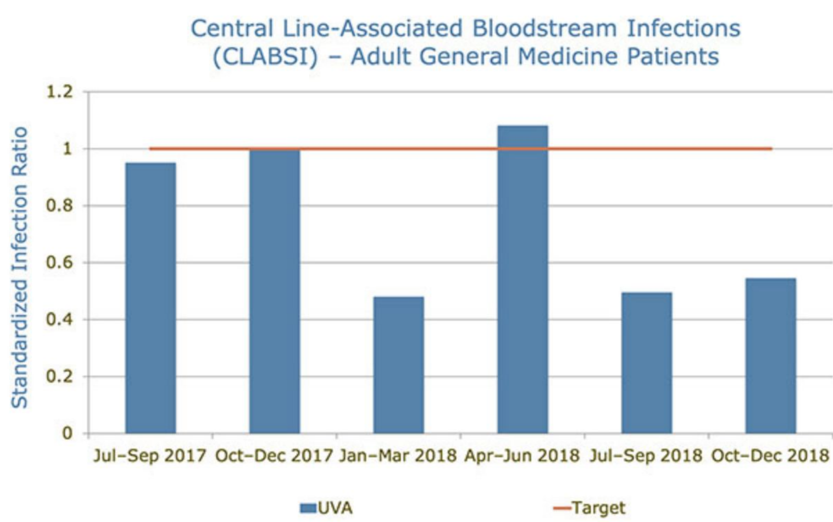
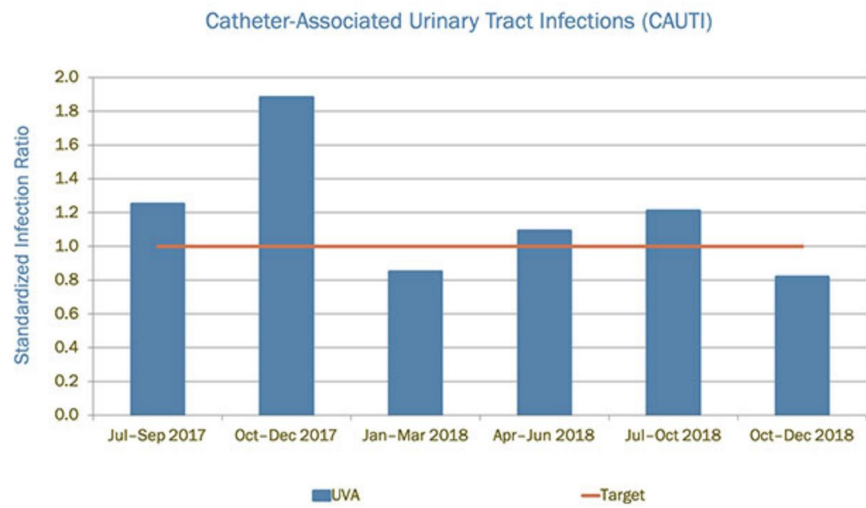


Figure 10: Catheter Associated Urinary Tract Infections



Medical Facilities

In an increasing complex world regarding healthcare, patients and other stakeholders possess numerous options when choosing the facility and method by which they receive care and interact with the healthcare system as a whole. A significant decision comes into play when considering and selecting the type of medical facility that patients decide to receive their care from based upon the services offered. Considering these factors in the scope of the project, it is essential that patients and other stakeholders possess the knowledge to make informed decisions about which type of medical facility they choose to attend and the potential risks associated with that choice. Within the bounds of this project focus, Hospital Acquired Infections (HAIs) pose risks mainly at the medical facilities discussed below.

Hospitals

Hospitals provide necessary and complex procedures for short-term care of patients with moderate, severe, and emergency health issues resulting from a variety of factors. Hospitals differ from other medical facilities with respect to the procedures they provide for patients in need and the focus demographic of patients of all kinds. Ranging from general health to surgeries to emergency and acute care, hospitals are designed to hold large patient populations in close proximity in order to treat as many patients in need given the wide range of procedural care they offer.

Ambulatory Surgical Centers

Ambulatory surgical centers offer specific and niche surgical procedures to patients that fall within a complexity range that may be too difficult to perform at a primary care doctor’s office but also elective enough that they need not be performed at an acute care hospital. These medical facilities offer outpatient and same day surgical care in a regulated and controlled environment that allows for the same level of outpatient and postoperative care for patients as most hospitals. However, most procedures performed at these ambulatory surgical centers can often be much cheaper than scheduled and elective surgeries at hospitals and offers an incentive for patients to utilize these facilities for most low-risk surgical procedures. Overall, ambulatory surgical centers provide a very specific function that is just one subset of acute primary care at hospitals.

Nursing Homes

Nursing homes are mainly used by and designed for patients and other individuals that require devoted attention and constant care for an extended period of time. Nursing homes possess the added benefit of extended care that differs greatly from acute primary care facilities such as hospitals, and can provide a viable option for care depending on a patient's specific needs. Physicians, nurses, and other staff members within nursing homes generally provide more intentional and devoted attention to patients, often assisting with both medical related tasks and other needs for patients that may prove too difficult for the patients themselves.

Hospital Acquired Infections (HAIs) in Medical Facilities

Considering the focus of the project with regard to offering a preventative and implementable solution that mitigates the spread of Hospital Acquired Infections (HAIs) in medical facilities, it is essential to consider the proliferation of these infections in each healthcare setting. Hospital Acquired Infections (HAIs) are defined to be infections that befall upon patients while receiving care appearing within 48 hours or as a result of their visit within thirty days. While different medical facilities were discussed previously, the namesake of Hospital Acquired Infections (HAIs) highlights where these infections are most proliferative: in hospitals themselves. More than 1.7 million Americans over the course of each year will acquire an infection within hospitals as a result of their treatment and care within its walls, and many others will go undiagnosed or unreported as well. Among that specified population, nearly 100,000 patients and individuals will die as a result of the spread of Hospital Acquired Infections (HAIs) which in most cases can be preventable if proper standards and policies are followed. Nearly 7% of all hospitalized individuals in the United States of America and other developed countries will acquire a hospital-borne infection as a result of their visit.

For this reason, the healthcare setting in which our team will focus its efforts of exploration will mainly include acute primary care hospitals. While infections can and do occur in any medical setting, other facilities including ambulatory surgical centers and nursing home possess infection rates far smaller than hospitals. Narrowing the scope of the project within this specific setting allows for an intentional and focused exploration of Hospital Acquired Infections (HAIs) within hospitals and what factors may lead to this unbounded proliferation of infection.

Size of Medical Facility with respect to Hospital Acquired Infections (HAIs)

While some hospitals across the country have been successful in reducing the rate of Hospital Acquired Infections (HAIs) as a result of new regulatory guidelines and penalty programs imposed on a national scale, the spread and rate of infections within these hospital settings have increased steadily within the last few years. Based upon analysis conducted by the CDC, Definitive Healthcare, and other both public and private reporting agencies, higher infection rates have an association with a variety of factors including increasing facility size and other compounding policy implementation factors. While a solution decreasing the overall size of hospitals is not feasible nor implementable based upon the nature of acute primary care facilities like hospitals to provide care for as many individuals as possible, it provides further insight into which hospitals specifically should be focused on given the increasing rate of some Hospital Acquired Infections in larger hospitals throughout the country. Other factors associated with larger hospital facilities include understaffing of personnel or increased volume of patients admitted. This allows the team to narrow its scope to focus on larger hospitals, which can expanded upon further comparing case examples of different hospitals by size and their rate of infections spread.

One such specific case study highlighting the differences between the rate of Hospital Acquired Infections (HAIs) based upon size is the different rates of infection within the University of Virginia Health System and Sentara Martha Jefferson Hospital, both located in Charlottesville, Virginia. Illustrated within the figures that follow, while both the University of Virginia Health System and Sentara Martha Jefferson Hospital have rates of infection that are not significantly different when compared against all hospitals across the country and national benchmarks, on average the UVA Health System along with its size, large patient population, and stretched staffing in some situations have a higher rate of Hospital Acquired Infections (HAIs) than Sentara Martha Jefferson Hospital. The following figures portray Hospital Acquired Infections as a comparison between the two hospital facilities with regard to both methods of transmission and pathogenic bacterial infection. Retrieved from https://www.medicare.gov/hospitalcompare/compare.html#vwgrph=1&cmprTab=3&cmprID=490009,490077&cmprDist=6.1,9.8&dist=100&loc=22903&lat=38.0335948&lng=-78.5887951.

Methods of Transmission Comparison

Figure 11: Bloodstream Infections

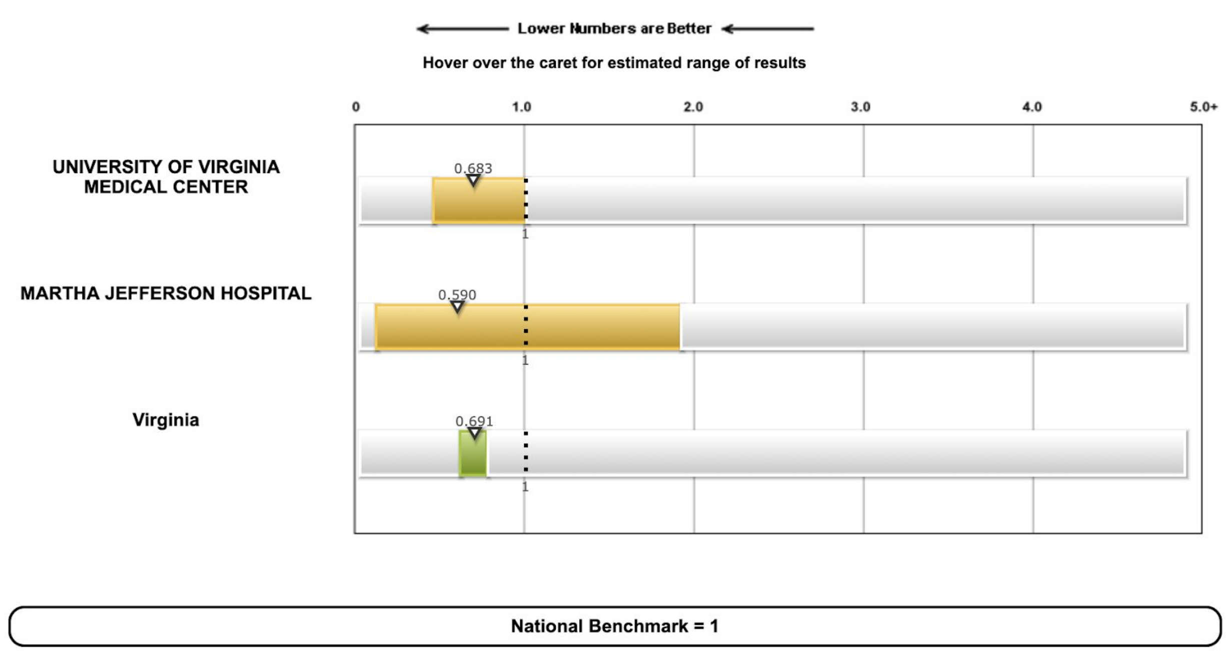


Figure 12: Urinary Tract Infections

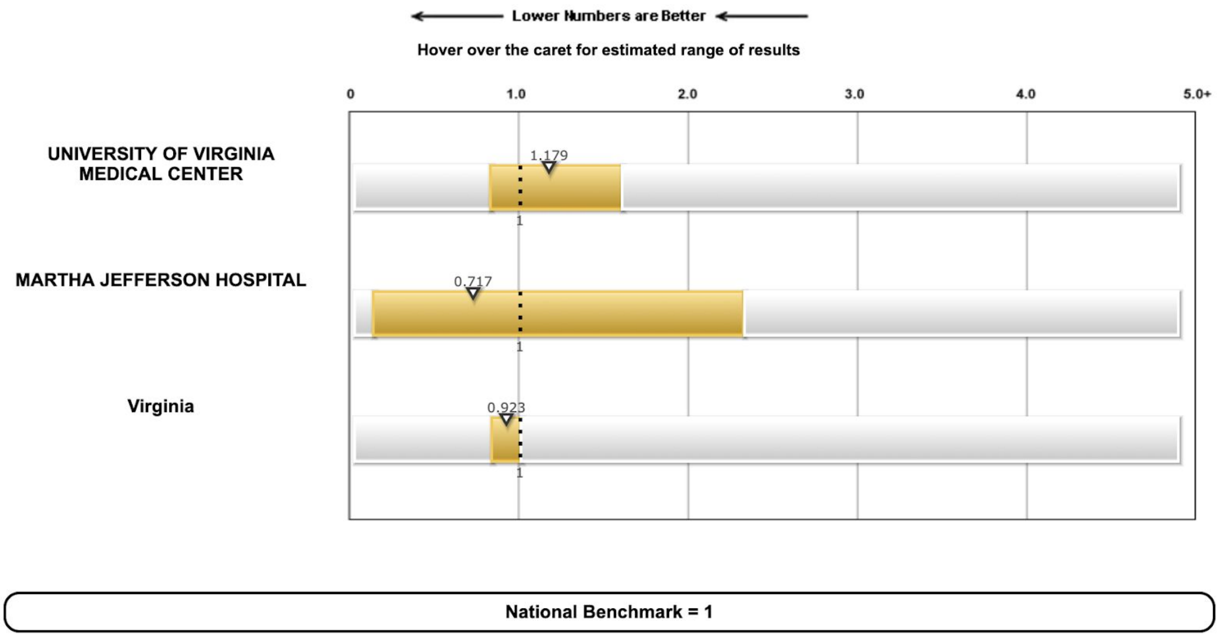


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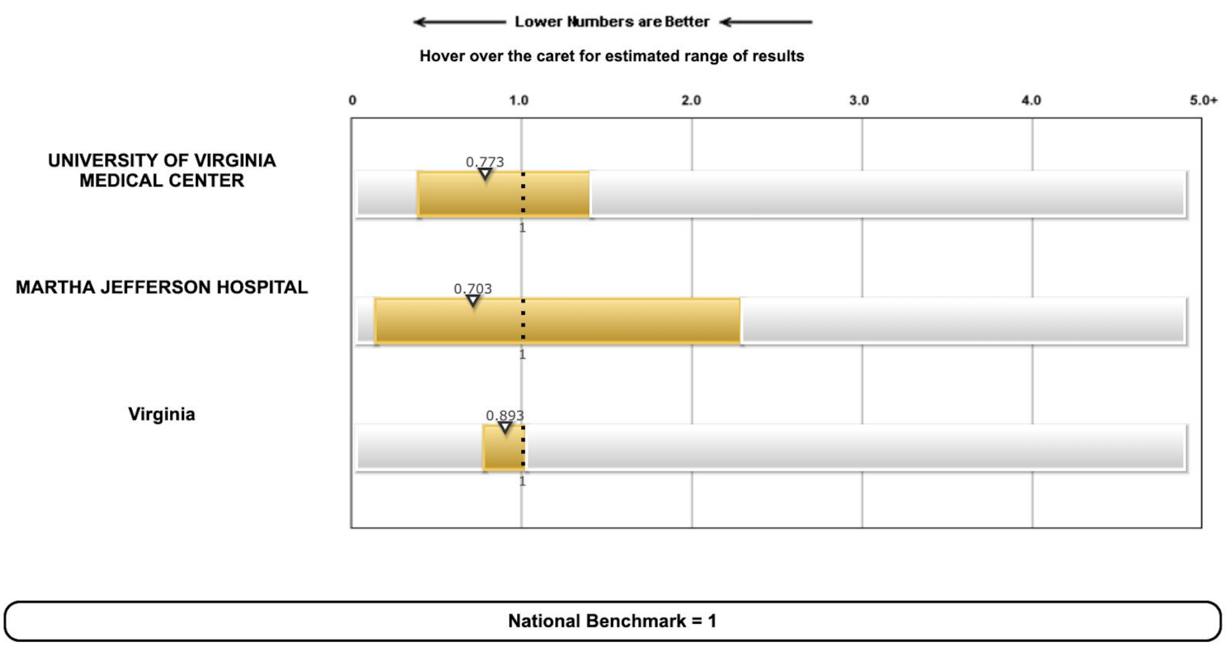
Figure 13: Surgical Site Infections



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Pathogenic Bacteria Comparison

Figure 14: Clostridium difficile (C.diff.)

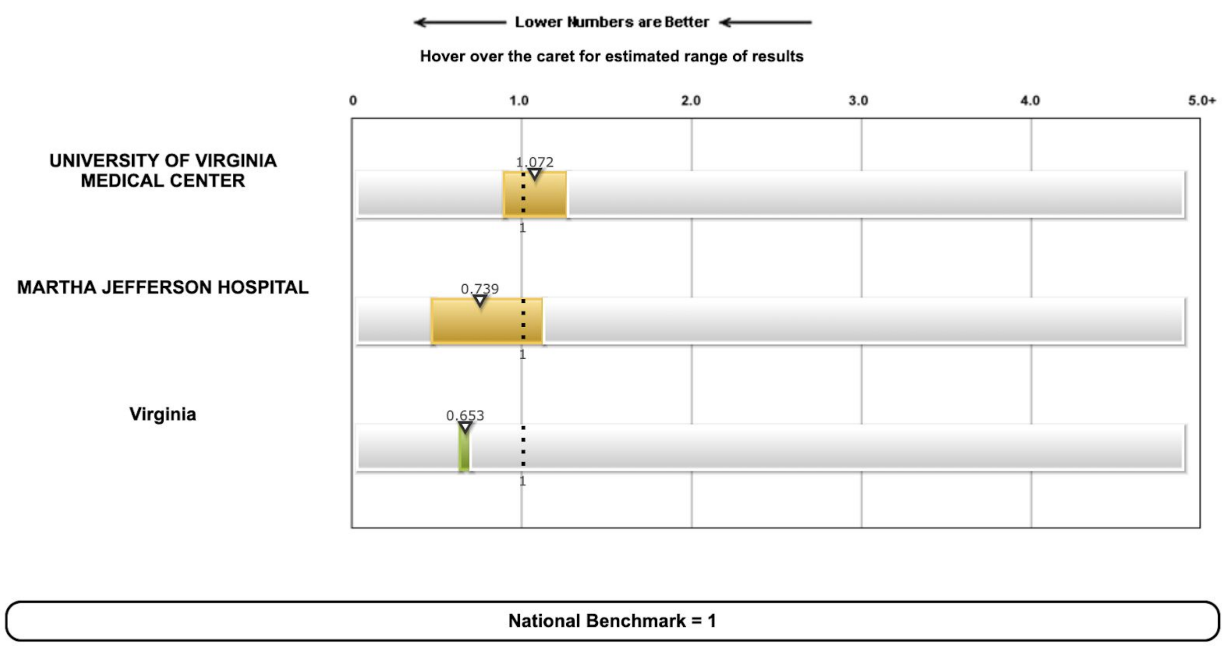

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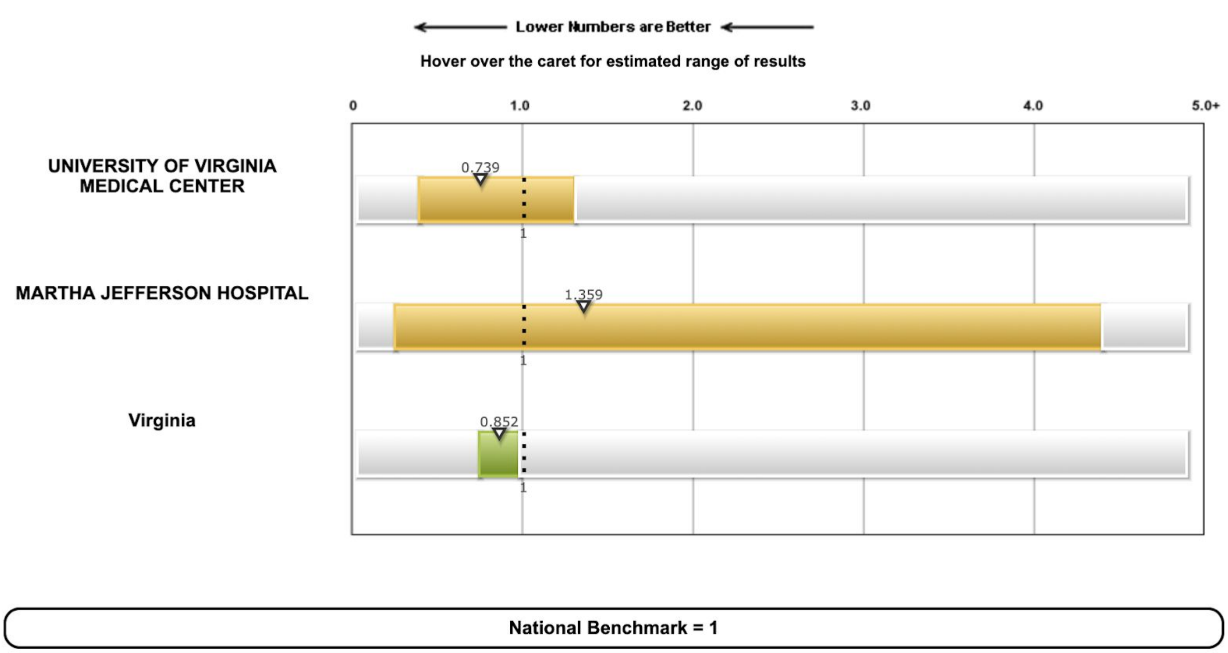
Figure 15: Methicillin-resistant Staphylococcus Aureus (MRSA)



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Policy Regarding Hospital Acquired Infections (HAIs)

National Policy

The implementation of actionable policy that is followed by all medical facilities is essential in providing the best care possible for patients while also decreasing the rate of Hospital Acquired Infections (HAIs) among the patient population. Current policy preventing the spread of these infections relies on a top-down approach with governmental agencies and national preventative measures providing the largest push for new Hospital Acquired Infections (HAIs) policy and legislation. These federal initiatives, however, allow for the opportunity of a recognizable and standardized policy procedure to prevent the spread of infection that not only can be adopted by acute primary care facilities such as hospitals, but also by all other medical facilities as well. Cooperation, coordination, and standardization are essential to enacting policy that will decrease the rate of Hospital Acquired Infections on a national scale.

Within the last few years as well, more attention has been brought to the issue of Hospital Acquired Infections through national media attention, public outrage, and an outcry for standardized and safe procedural care for patients within the healthcare setting that are affected. This added public platform has allowed for increased initiative in pressuring for actionable policy change, and as of January 2011, thirty-two states along with the District of Columbia have passed laws and other legislation pertaining to Hospital Acquired Infections (HAIs) prevention, regulations, and reporting. While this is a step in the right direction, it is important to consider the ramifications of a not standardized and not widely adopted policy implementation that may provide more complications with regard to Hospital Acquired Infections in the future.

Local Policy

In order to address policy implementation regarding Hospital Acquired Infections (HAIs), it is necessary to consider the disparities between national and local policy. In many cases, there exist difficulties following national policy that is instituted on a local level amongst individual hospitals. While state legislation and policy from the Department of Health does act to promote a relationship between national policy and local hospitals, not all governmental policy regarding the prevention of infection spreading is followed, maintained, or sustained reliably amongst different hospitals. As previously referenced in the figures showing a comparison of both methods of transmission and pathogenic bacteria in the University of Virginia Health System and Sentara Martha Jefferson Hospital, discrepancies exist with regard to policy implementation reflected in the spread of Hospital Acquired Infections (HAIs) just in these two hospitals as a case study comparison.

Within Virginia as a sample size of hospitals, Sentara Healthcare System, which acts as an umbrella for many hospitals throughout the state, exceeds expectations of infection prevention with regard to those acquired within hospital settings. Not only on a local scale when comparing Charlottesville hospitals in which Sentara Martha Jefferson exceedingly outperforms the UVA Health System with regard to the proliferation of Hospital Acquired Infections (HAIs). This is common amongst other Sentara Healthcare facilities and hospitals within Virginia, where Sentara Leigh Hospital and Sentara Virginia Beach Hospital are the first hospitals in the state recognized as Centers of Excellence in Managing Infection Risk. These hospitals improve upon current blanket policy that has been imposed and add new policies and solutions in order to facilitate a safe, clean, and healthy medical space. While it is clear that policy ranges from a national, state, and local scale of implementation, viable solutions to the issue of preventing infections from spreading in healthcare settings required innovative and implementable solutions in order to keep the patient population healthy without fear of Hospital Acquired Infections (HAIs).

5. Mission Statement

To create a safer hospital environment for patients by improving the quality of care of those at risk through prevention of Hospital Acquired Infections (HAIs). Our goal is to design a solution that will reduce the spread of infections in hospital settings.

6 Generation and Selection of Requirements-based design Concept

Generate Design Requirements

**** All members of the group contributed equally to each of the requirement tables.***

Table Legend

Importance

- 1 - Essential
- 2 - Important
- 3 - Hopefully Achieved

Qualitative

- P - Performance
- F - Financial
- S - Sustainable

Specification

- A - Acceptable
- I - Ideal

Table 2: Materials Acquisition Requirements

Requirement	Importance	Qualitative	Metric	Specification
Materials will be obtained from local medical device manufacturers within the surrounding Charlottesville area.	3	S	Percentage of materials acquired from local manufacturers	A: 75% I: 100%
Materials obtained for creation of product to reduce the spread of infections through pathogenic bacterium must be non-toxic to the environment, workers, and patients.	1	P, S	Product composition percentage of toxic materials	A: 5% I: 0%
Materials will be selected with quality production and	1	P, S	# of patients and/or staff	A: < 10 people injured

safety in mind for the purpose of patient safety within hospitals and other medical facilities for applicable use.			injured by product	I: 0 people injured
Materials that make up the final product solution in reducing the spread of infections in preventing Hospital Acquired Infections (HAIs) must be properly disposed of as medical waste and does not detrimentally affect the environment.	1	S	Percentage of medical waste that are sustainably disposed of	A: 90% I: 100%

Table 3: Manufacturing and Transport Requirements

Requirement	Importance	Qualitative	Metric	Specification
Implemented product and solution for the intended use of mitigating the spread of infections must be sterilized through manufacturing processes.	1	P	Percentage of devices properly sterilized	A: 98% I: 100%
Packaging of manufactured product implementable in medical facilities must keep sterilization of device until eventual use.	1	P	Percentage of devices that are not compromised by packaging	A: 98% I: 100%
Transportation of manufactured product must not compromise the sterilization, structural integrity, or effectiveness of the proposed solution.	1	P	Percentage of devices that stay sterilized during transportation	A: 98% I: 100%
Transportation of manufactured product for use within medical facilities must be shipped securely and handled carefully in its travel to destination.	2	P	Percentage of shipments that are not delivered and accounted for	A: 95% I: 100%

Table 4: Consumer Use and Product Maintenance Requirements

Requirement	Importance	Qualitative	Metric	Specification
The device shall be simple and user friendly in order for it to be accessible to any hospital staff	1	P	User survey results (rating)	A: 7 I: 10
The device/policy shall require minimal to no maintenance	2	P, S	Number of maintenance issues per month	A: 3 maintenance issues I: 0 maintenance issues
The device/policy shall be able to prevent/remove all bacteria/infection types	1	P	Percentage of bacteria removed	A: 85% I: 100%
Admins shall be required to undergo module training to understand HAIs and device usability	3	P	Percentage of modules completed	A: 100% I: 100%

Table 5: Costs and Personnel Requirements

Requirement	Importance	Qualitative	Metric	Specification
Acquisition/upfront cost for hospitals (ie. how much will it cost to initially implemented a policy or by a device.) We need to know how much hospitals are willing to pay for starting costs to ensure that we stay well within the parameters.	1	F	Within the Hospital's Allocated funds to fight HAI	A: 50% I: 30%
Ongoing costs - what are the continuous costs going to be, for example will the machine cost maintenance or electricity. For a policy what will the estimated costs per year and for continued compliance.	2	F, S	Within the Hospital's Allocated funds to fight HAI	A: 50% I: 30%
Required Training - what will be the required initial training in order to learn how to use a new device. Additionally, for a policy, what would the initial training be required to start the policy and what would be the requirements for maintaining a level of proficiency (annually, biannually,)?	3	S	Should not detract significant time to initially train healthcare workers	A: < 10 hours I: < 4 hours
Personnel that will administer the product/process - how will it be implemented in the hospital and what would the distribution of devices be?	1	S	Number of additional people to manage new systems	A: 1 - 2 per hospital I: No additional personal

Generate Solution Concepts

Internal Research and Brainstorming

Aria Kumar's Brainstorming

1. Foot sensor that automates sink water

Team member hand cleansing statistics show that there is still a small percentage of noncompliance. Doctors/nurses are less likely to wash when they have a busy workload and much more likely to wash their hands under this system of supervision. The idea behind the sensor is that as soon as the doctor steps into the room, the sensor detects the footsteps, and the sink will automatically turn on. As a result, the doctor must wash their hands in order to turn off the sink. Assuming the patient is conscious during this process, a doctor or nurse will have a higher inclination to their wash hands. In an effort to conserve water, it would be better to put a time limit for how long the water runs, but it should be enough for the doctor to feel obligated to turn it off. A major problem is that this could potentially be annoying if the doctor/nurse steps out of the room and reenters shortly after they have already washed their hands. It can also be problematic if the visitors are constantly being forced to rewash hands if they have only stepped out for a minute.

Strengths:

- Adheres to the idea that doctors are more inclined to wash hands when watched
- Water running is not easy to ignore and cannot be forgotten
- Usability

Weaknesses:

- Unable to easily be repaired by user
- Potential for water wastage
- Reentering after stepping out for a second could be inconvenient

Questions:

- How would maintenance issues be handled?

2. TV Screen Checklist

After talking to Eve Giannetta, manager of infection control at the UVA hospital, I discovered there is an insertion bundle that revolves around using a checklist in order to prevent central line associated bloodstream infections (CLABSI). Ideally, the nurse must observe and fill out a checklist as the doctor performs the insertion of the line. In reality, the nurses sometimes must handle their own patients and the doctor proceeds to the procedure without anyone watching. The nurses end up filling the checklist out after the procedure is complete, which defeats the purpose of the checklist. My idea is to have a screen outside the room that displays the checklist and have the nurse fill out a virtual checklist (perhaps on an ipad/tablet) that will sync to the tv screen. As a result, everyone will be able to see a live viewing of the checklist being filled out and the nurse would be more obligated to be in the room and carefully observe every step.

Strengths:

- If anyone else in the room catches a violation of the checklist before the nurse, it can be brought to the attention of the doctor faster
- Nurse cannot quickly fill out the checklist without observing if everyone in the room is there to watch him/her complete it
- Could be inexpensive

Weakness:

- Could run into difficulties setting up
- Could still be ignored

Questions:

- Who is in charge of making sure the checklists are filled out?

3. Time stamp for checklist

Going off my checklist idea in internal idea #3, another potential idea could be adding timestamps when nurses check off something on the checklist. This would motivate nurses to take their time and actually observe the procedure being enforced. If the timestamps indicate that the form was completed after the surgery was performed or if the time gaps seems suspicious, then perhaps the nurse may need to redo their orientation training. This checklist could be on an app and data can be sent to a database. The app should send an alert to an official if it detects something suspicious in the checklist.

Strengths:
- Inexpensive

Weaknesses:
-

Questions:
- What are the consequences if nurses don't fill out the checklist?

4. Small waterproof robotic bug device that emits UV light/heat in pipes

Waterborne infections transmitted through the hospital plumbing system is also a major issue according to Dr. Guilford. He mentioned that the use of UV light is currently used in many of the sanitation methods and is used for disinfecting the trap (also known as the U-bend) on sinks. He also talked about a device under the sink that uses heat to kill all the bacteria. In addition, I read that some hospitals are using robots that emit UV light in order to disinfect the patient room. To eliminate the bacteria that colonizes the water pipes, my idea was to create a small waterproof robotic bug that can be sent through the hospital plumbing and use its sensor to detect bacteria and then emit either UV light or heat to get rid of it. The robotic bug would be controlled using an app.

Strengths:

- Immediately gets rids of the bacteria in the pipe
- Small enough to still allow for efficient drainage

Weaknesses:

- Difficulties with maintenance of the app
- Difficulties with implementation of the device
- Could get lost inside pipes
- Expensive

5. Virtual Checklist that requires scanning of QR code

Another idea to address the problem that nurses aren't properly filling out the checklist is to create a virtual checklist (on an app) and to have the nurses use a fitbit like device to scan a QR code in order to be able to check off an item on the checklist. For example, if the first item on the checklist requires the nurse to make sure the doctor has taken care of hand hygiene, the nurse must use his/her fitbit device to scan the QR code on the sink in order to proceed to the next item on the checklist. This ensures that all of the items on the checklist are thoroughly being checked by the nurses.

Strengths:

- Easy to use

Weaknesses:

- Maintenance of the app
- Maintenance of the scanning device

Rex Focht's Brainstorming

1. Non-Stick Coating

A common issue arising from pathogenic bacterium growth of all forms within hospital settings is the tendency of bacteria to grow and colonize on varying surfaces within the hospital, including but not limited countertops, handrails, desks, and floors. Bacteria in this way are able to colonize and grow on surfaces within hospitals that spread Hospital Acquired Infections (HAIs) as a result of the small crevices and structure of surfaces present. Bacteria produce small protein and molecule chains that allow them to create an adhesive surface that bonds to the hospital surface to form a foundation to stick and latch onto as they grow. This process forms a biofilm of bacteria that allows for the colonization and spread of bacteria within the hospital leading to heightened risk of infection being spread from surfaces that are commonly used and touched by hospital staff, nurses, physicians, patients, and family members during routine hospital operations. Preventing bacteria from colonizing on surfaces would lead to a major reduction in the spread of infections acquired by patients within hospital settings. The solution concept for a non-stick coating in hospitals is based upon a similar concept idea in non-stick surfaces within cooking that rely on Teflon coating for cooking instruments that do not allow food substances to form adhesive bonds to the instruments themselves. This theory and application applied to hospital surfaces would create a similar non-stick surface coating derived from amino acid chains that prevent the building of protein chains by bacteria and do not allow these bacteria to grow and colonize on surfaces.

Strengths

- Easy application of non-stick coating on surfaces that would require spray or rub to quickly apply coating
- Addresses both common spaces within the hospital and patient rooms in order to minimize the spread of infections
- Could be applied during general cleaning procedures and would not require licensed clinicians to perform task

Weaknesses

- May have to apply multiple coats of non-stick chemical application in order to cover all surfaces within hospital
- Would be costly if not mass-produced through efficient and cost-effective manufacturing processes
- Would have to reapply coating in undetermined amount of time in future given the coating is not a permanent application and must be used multiple times
- Covering all surfaces present within the hospital with non-stick coating would create an extremely time-intensive process

2. Adaptive and Strict Isolation Procedures

One of the most difficult issues to handle that hospitals face when tasked with minimizing the spread of infection is the containment of infections that are already present within the hospital. When one patient undergoing treatment and care for a communicable infection as a result of pathogenic bacteria is in the hospital, all parties involved with the patient's care and those in close proximity now have a much higher risk of spreading or contracting the same infection. This heightened risk includes hospital staff, nurses, and physicians treating the infected patient as well as other patients for unrelated illnesses within the hospital that are in adjacent rooms, in close proximity, or being treated by the same clinicians within the hospital. Other parties at risk for contamination and possible carriers of infection are visitors and family members that should not be allowed to close proximity to the infected patient that may contract the communicable infection as well. Following isolation procedures for patients with infections that are transmittable is a key component to minimizing the spread of Hospital Acquired Infections (HAIs) and is a practice that is not always strictly adhered to while patients are being treated. Understanding, emphasizing, adapting, and strictly following isolation procedural guidelines cannot be stressed enough when it comes to mitigating the spread of infections within hospitals. The solution concept generated within this iteration depends largely on a human factors adherence to procedural guidelines and policy execution within hospitals. Isolation procedures should not be a generalized process with regard to different types of infections within hospitals, and while it may be more complex to adapt isolation procedures to a variety of possible infections that patients may have, it is essential to understand and correctly follow the guidelines imposed by the hospital to achieve the smallest probability of spreading the infection.

Strengths

- Most hospitals already employ multiple isolation procedures to help quarantine patients at risk of spreading communicable infections to other areas of the hospital.
- Implementation of new policy would be able to be built upon and revised through iterations of previous foundational policies that came before it.

Weaknesses

- Policy and procedural guidelines are not always strictly adhered to in a hospital setting given a variety of circumstances, normally dependent on time and convenience hospital staff have to perform these isolation procedures.
- New isolation procedures adaptive and specific to each pathogenic bacteria and related infection may be too complex given current generalized isolation procedures.

3. Two-Step Mechanical and Chemical Cleaning

General cleaning is a fairly basic but foundational aspect of minimizing infection spread within hospitals and other medical settings. Normally, cleaning is conducted daily in shared spaces within hospitals and immediately after patient discharge within patient specific spaces around the hospital. Cleaning is defined as a mechanical process that uses water, disinfectants, and other detergents that pick up and bind bacteria, molecule chains, other small particles within the fluid mixture used for cleaning. Cleaning must be thorough and emphasized as an essential routine procedure that cannot be lazily administered under any circumstances. The solution concept relating to this idea of more thorough cleaning practices is based upon a two-step process that combines both mechanical and chemical processes that eliminate the highest percentage of bacteria that spread infections around the hospital. Thorough but purely mechanical cleaning processes pick up, clear, and dispose of approximately 90% of all bacteria. Chemical cleaning that actually breaks down, kills, and eliminates bacteria rather than trapping them through a mechanical process must be added to general cleaning practice guidelines that increase the likelihood and threshold of killing off as close to 100% of all bacteria present as possible regardless of the medical setting. There are a variety of chemical procedures and compounds that can aid with this added chemical cleaning process, and this two-step cleaning initiative should be implemented across all hospitals to ensure every possibility of minimizing the risk of infections spreading.

Strengths

- Added chemical cleaning steps would provide an extra procedural layer of protection against residual bacteria left behind in both common spaces and patient rooms throughout the hospital.
- Chemical cleaning in conjunction with mechanical cleaning would increase the likelihood and percentage of reducing bacteria present even more than standard mechanical cleaning procedures.

Weaknesses

- Added chemical cleaning steps would require more time cleaning in each space within the hospital that would be multiplied out and exponentially increasing time cleaning if not easily implemented.
- Fumes from chemicals used to kill off bacteria rather than capture them could pose dangers and toxic elements to patients, visitors, and hospital employees within cleaned areas if not properly fumigated.

4. Patient-Room Sterilization of Instruments

A very difficult issue that hospitals face is the proper sterilization of different instruments and tools that are used multiple times in order to complete general procedures, including but not limited to surgical instruments, stethoscopes, and other examination tools. Currently, single-use medical instruments are properly disposed of in medical waste baskets within each patient room that minimize the risk of infections spreading throughout other parts of the hospitals. Multi-use medical instruments are not currently sterilized in a similar way before exiting the patient room and collected from room to room before being transported to a centralized location for sterilization. The solution concept that is the foundation of this idea would be to have a similar disposal system as single-use medical instruments in place within each patient room that could funnel the multi-use medical instruments through a chute system into a centralized sterilization site without having the instruments exit the patient rooms within common areas that could provide increased contamination risk as they are transported and collected throughout the hospital on their way to the centralized sterilization site. This solution concept will allow the medical instruments to be more properly transported after usage without increasing the risk of spreading infection if they are contaminated after patient examinations.

Strengths

- Used and contaminated medical instruments would be confined to patient rooms without having to enter common spaces in the hospital that would pose a risk of increased spread of infections.
- Easily implementable and usable with a receptacle bin for medical instruments would be located conveniently within the room the procedure is being performed in.

Weaknesses

- Hospitals would have to reorganize infrastructure to implement a chute system that centralizes and efficiently collects used medical instruments for sterilization.

5. Equipment Checklist

This solution concept is based upon the equipment aspect of contamination and isolation procedures when minimizing the risk of spreading infections from a quarantined or contaminated patient room. An equipment checklist implemented prior to entering the patient room would not only provide hospital staff another way to double check that they have all the equipment necessary to perform the task and procedure at hand, but also it would minimize the need to enter and exit the quarantined patient room multiple times if the clinicians forgot certain equipment after already entering the room. While this solution concept is fairly simple in nature, it provides a reinforced and extra step of security in making sure all the proper equipment has been obtained and that is properly functioning in the time of need when conducting procedures and treatments within patient rooms that have communicable and transmissible infections that could spread and detrimentally affect all individuals that come in contact with the patient and within the surrounding area.

Strengths

- Equipment checklist would be easily implementable with guidelines and checks for all standardized equipment needed before entering a contaminated or quarantined room.
- Checklist for equipment is similar to other standardized practices within the hospital and would be easily teachable and intuitive to understand.

Weaknesses

- Would add increased time in preparation to enter a contaminated or quarantined room if there is an emergency present that needs to be addressed.
- Hospital employees may be resistant to performing more tasks prior to completing procedures and equipment checklists may be overlooked.

Alexander Knoop's Brainstorming

1.) UV light purification of U-bend (plumbing trap) of toilets and sinks

- The use of UV light is currently used in a number of sanitation methods and was brought up by William Guilford as a potential method for disinfecting the trap (also known as the U-bend) on sinks
- Research has shown that heat and UV light are highly efficient ways of killing bacteria with limited ability for bacteria to readily adapt to this form of attack, unlike increased resistance to antibiotics and
- The current method that is being researched is heating up the area to prevent bacterial growth, however this comes with 2 key requirements, one must avoid burning people and some bacteria are heat resistant to a point that would normally be harmful to people. This still leaves concerns about splash and
- The use of UV light bulbs as a method of purification is not a new one. UV light is already a method of water purification in backpacking and has been considered a s an option for plumbing trap sterilization. However, previous designs suffered from a lack of efficient drainage due to the inserted bulb. This seemed to be the logical step because one could simply insert the bulb down the drain and just let it purify on its own, however this leads to several logical problems, the first is the lack of drainage, the second is the uncertainty of placement, and the third is the wiring of the bulb.
- This has led to two main ideas for making an efficient sterilization method that doesn't suffer from these problems.
    - Could alter the design and be made more efficient by embedding the bulb in the pipe, as opposed to inserting a bulb into the pipe. This could be accomplished by cutting a hole into the side of the U-bend and inserting the bulb into the pipe directly. directly, then seal it off with putty/plaster
    - Could remodel the whole U bend and build a window for the bulb to be put up to, then one could easily turn the bulb on periodically and swap it out

2.) More Sterile Ventilator

- Ventilators are an essential tool in the hospital setting are used to aid in the
- A major HAI is the pneumonia acquired from ventilators, this is a potentially lethal condition and the risk of contracting it drastically increases after 48 hours of being on a ventilator.
- A potential method would be to use a copper coating on the instruments to reduce bacterial growth. Copper has antimicrobial properties and has been shown to inhibit bacterial growth.
- Shark skin? Method for reducing bacterial growth that with a specific patterns

3.) Quartz Glass U - bend Tube that can be radiated/ UV light or heated.

- We could use a glass tube as a method to allow the U-bend to be more susceptible to heat and radiation allowing for the other
- This replacement of the part would better enable the use of other methods for purification.
    - Glass could easily be heated without warping or damages in order to kill bacteria, this could be operated after the water was done flowing and wouldn't need to always be on
    - If the UV method was used, no specialized bulb would be required, we could simply use any high powered UV bulb and place the bulb up to the glass (provided the glass effectively transmits radiation)
    - This also would allow for easier attachment to the trap and the potential to replace the part on sinks without having to rebuild the sinks.
    - Glass doesn't degrade with time and would not have issues with corrosion or unfavorable pH's
    - Unfortunately one weakness to this plan is that this replacement would be quite expensive

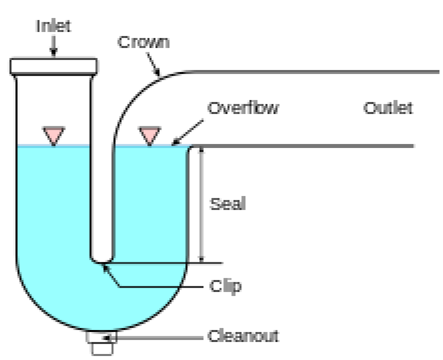


Image of the structure of plumbing trap (u-bend) works, retrieved from: https://en.wikipedia.org/wiki/Trap_(plumbing)

4.) Spreading awareness of infection prevention by having patients take an active part in the cleanliness.

- This method is slightly different because rather than a direct training or new technology, it would require interaction from the patient to check that the healthcare provider practiced good sanitization and washed their hands
- This would enable a method for patients to report if something obviously wrong occurs in the sanitization procedure.
- Main issue is patients are not experts and are not expected to be

5.) Increasing the effectiveness of the protocol for reducing HAIs through increased oversight. This could be accomplished by increasing the accountability for compliance with procedures already in place.

    - This could be accomplished by requiring immediate feedback after a healthcare provider enters or leaves a room.
    - One could record whether the sink turns on and for how long, or if hand sanitizer was dispensed. This would keep more careful track of whether these actions were actually taking place rather than just being checked off as complete
        - This could be stored in a centralized system that could be reviewed at the end of the day
        - The entire system could be automated by relatively simple circuits that just measured whether or not something was activated
        - Would allow supervisors to review activity easily and check with which hospital member the time of activity, or lack of activity occurred at
        - This would not compromise privacy, but would increase accountability and back up the data recorded on checklists.
        - This method would probably be used as a method of verification rather than the main source as it would have trouble accounting for random interactions and potential patient use of hand sanitizer or sinks.

6.) Robot that is designed to disinfect the room by spraying an antimicrobial solution

    - This could function to better sterilize surfaces without necessarily placing a human at risk
        - Could be used to sterilize known contaminated areas
        - Would be especially helpful for infections diseases that can survive on surfaces.
        - The spray could be alcohol based so that it would evaporate quickly and kill anything on the surface

- It could be designed to dissolve biofilms with the spray, and scrub after the area has been sprayed
- Could have a predetermined course to take through rooms when vacated to ensure that the entire room is scrubbed thoroughly → Similar to a roomba's pathfinding.
- Could function as an arm like attachment on a mobile base that allows for cleaning different areas.

Bezawit Bogale's Brainstorming

1. Interactive Application

This solution concept connects people virtually through the use of mobile applications. This application consists of components including:

- Information and Resources
  - Includes statistics and awareness-based information about Hospital Acquired Infection that educate workers. The information posted will be updated often to continuously keep workers up to date. The information on this application is both about the specific hospital and organizations outside including other hospitals, CDC, and other governmental/private platforms. For information about the specific hospital, the respective hospital should have a team who is responsible for data collection which is helpful to see where the facility is when it comes to their infection control process and measures.
- Gamification Aspect
  - Can have a specific motive or general.
  - A game that is directly about the concept of sanitation or a simulation that is a build of story of characters with indirect messaging about hand hygiene/following hospital regulations.
  - Connects works and encourages competition.
- Daily Point Collection System
  - Is a log that works perform everyday about their hygiene
  - Comes with a reminder system reflecting the daily logs and points earned.
- Sharing Capabilities
  - Allows workers to share scores and other information through social media.

Strengths

- Educated while having fun.
- Targets individuals from personal perspective as it is downloaded on individual phones.
- Constantly reminds people to think about hygiene and infections.
- User friendly as applications already exist on mobile phones and people know how to navigate them.

Weaknesses

- Limited to cell phone users
- Limited to a specific age group
- Requires training/navigation sessions
- Expensive to implement

2. Creation of Leadership Positions

This solution concept builds on existing guidelines in hospitals. It creates a specific position for people to monitor hourly logs of checklists done by doctors and nurses. The person in charge should be an already existing worker like a nurse. This allows for the job to be effective as it is led by a person who is already familiar with the staff and ins and outs of the hospital environment and guidelines. People can conduct hourly monitoring of hand hygiene and help with module training for newly hired hospital workers.

Strengths

- More effective measure because hospitals are hiring people familiar with the environment specific to the hospital.
- Encourages workers to stay committed as the payment acts as an incentive and others to follow the guidelines effectively because they are motivated by people who already are familiar with them.

Weaknesses

- Funding for this position can be limited.

3. Patient and Visitor Education

Implementing sessions for patients about Hospital Acquired Infections to expand awareness and give them the ability to monitor workers routine. This invites people beyond hospital works to the fight to decrease Hospital Acquired Infections and bring the matter right to the hands of patients themselves. I believe this is important because it is often the case to give hospitals full responsibility when it comes to patient care. However, workers are not the only groups that make up a hospital. Patients and their families also contribute to the overall effectiveness of a hospital whether they are directly or indirectly involved. This solution includes everyone to the process of increasing hospital's infection performance. After all, it is the patient that has to deal with more hospital stay, unnecessary hospital payment, and complicated health status.

Strengths

- Everyone will be responsible
- Patients have the chance to prevent themselves from infections
- Additional reminder system about infection guidelines/protocols for hospital workers.

Weaknesses

- Limited to patients who are conscious
- May not be consistent

4. Checklist Modification

One issue that contributes to the transmission of Hospital Acquired Infections is the ignorance/lack of commitment to complete the infection protocol checklist effectively. Therefore, besides making sure that the checklist is done, it is important to look into what components are listed to get checked off. Are the right questions part of the checklist? Why do hospital workers neglect their due diligence in completing the checklist? The two questions I believe are important as they play a role in the overall movement to reduce Hospital Acquired Infections. Instead of listing endless things to be answered, a shorter but effective list of things can be easier and less time consuming because hospital workers are often in a rush (especially if there is understaffing).

Strengths

- Increases quality and efficiency
- Altered to a specific hospital that allows an in depth data collection and evaluation to implement.

Weaknesses

- Face difficulties to approve the adjusted/added questions/protocols as hospital guidelines are often created by a third party like CDC and have the tendency to abide by the generic rules that should work for every hospital.

5. Hand Wash Technology

According to the CDC, many instances to avoid Hospital Acquired Infections is through consistent proper hand washing. Therefore, it is important that hand washing guidelines have to be respected, mainly because it is cheaper and more efficient than other methods of Hospital Acquired Infections preventions. However, it is reported that hand washing is usually forgotten/ ignored by those who are directly in contact with patients. Therefore, a technology that ensures handwashing and holds people accountable for their actions is an ideal solution to the issues around handwashing. What I suggest is a technology that comes with the hand wash area and record data. This data can be information about who washed their hands and how long they washed before and after their visits with patients. This way, the hospital has information on the worker's commitment to handwashing and can track down the responsible person. This is a measure that enforces accountability to remind people about their responsibility.

Strength

- Reminds people washing hands properly each time and that there will be consequences if they do not follow the guidelines.
- Because the system is attached with a data collection system, it is easier to track the right people.

- Helps for conducting annual/monthly research as the system provides data.

Weakness

- Can be costly

6. Single Use Sampling

Making sure the cleanliness of the patient's room is an essential protocol to fight Hospital Acquired Infections. Although there are many ways hospitals clean patients' rooms and equipment, there is an issue with to what extent the rooms get cleaned. That is why an additional method that ensures every part of the room is as clean as it should be. One idea I have is to include a step in the cleaning process using a sample method. The process starts by taking a sample of a specific area by brushing using a particular material that comes with a reader that reports whether the area is clean or has bacterial contaminants present. The reader responds within a short period with either green or red color. Green for clean and red for not clean.

Strength

- Ensures the cleanliness of patient's room
- Easy to use
- Quick to use

Weakness

- Can be expensive
- Malfunction with the reading can happen

Group Brainstorming

1. Medical Equipment and Tools Sterilization Box

The concept behind this solution idea builds upon a previously generated individual brainstorming concept that addressed the need for the proper transportation and sterilization of reusable medical instruments within a hospital setting. Further iteration upon this idea has expanded and improves the capabilities of this solution concept. Rather than employing a chute disposal system for centralizing used medical instruments for each patient room, a portable sterilization containment unit will be employed in each patient room for the immediate containment and lockup of medical instruments prior to transport to a centralized hospital sterilization area. Each containment unit will take in used and contaminated medical instruments and then lock itself to perform preliminary chemical sterilization procedures in each patient room. The containment unit would only be able to be unlocked by approved hospital staff after they are all collected from each patient room and transported to a centralized hospital sterilization area. This process and solution would still minimize the interaction with used and contaminated medical instruments and provide an added layer of security that ensures the minimization of the spread of infection as a result of bacteria from contaminated medical instruments.

Strengths

- Containment units would be easily implementable within each patient room.
- Dramatically decrease interaction with used and contaminated medical instruments by any individual after a procedure is performed and during transportation before sterilization.
- Would add multiple steps of sterilization to ensure proper cleaning of medical instruments that would be reused to perform other procedures at a later time.

Weaknesses

- Providing a containment unit within each patient room would not be a cost-effective approach and would dramatically increase hospital spending.

2. Smart Hospital System

The concept behind this solution idea is founded upon basic cleanliness and infection control prevention methods already employed that rely on proper hand washing of all individuals, not just hospital employees, within hospital settings in order to minimize the spread of bacteria and infections. Proper hand washing is one aspect of this solution concept and also one of the most simple but effective ways to decrease the spread of bacteria between individuals within hospitals, and a hand washing reminder system using lights reminders at every sink within bathrooms and outside patient rooms as well as voice playback reminders that would ensure and reinforce this procedural guidelines that may not always be properly followed. Other aspects of this solution concept include automated sinks that turn on when entering patient rooms to ensure proper procedural guidelines as well.

Strengths

- Simple but extremely effective way to add extra reminder to properly wash hands in order to minimize the spread of bacteria and infections.

Weaknesses

- Reminder systems could be costly with electronics and software needed for the system and implemented on a hospital-wide basis.

3. Waterless Patient Rooms

Water contaminated with bacteria that spread infections is an extremely important issue to consider within hospital settings when attempting to minimize the risk of infections being more widespread. In many cases, bacteria form, colonize, and grow within plumbing and sink systems throughout the hospital, including patient rooms. The solution concept being addressed suggests that hospitals remove all water disposal systems from patient rooms so that there is no potential for bacteria to grow within these environments. By decreasing the available spaces for bacteria to grow within patient rooms, these areas become cleaner and safe for all individuals that interact with and visit patient rooms throughout the hospital.

Strengths

- Waterless patient rooms reduce bacteria growth and colonization.
- Solution concept decreases available areas that bacteria have to use as suitable environments to grow in.

Weaknesses

- Many hospitals could not and would not be able to redesign their overall infrastructure and remove all sinks within these areas to make sure all patient rooms are waterless.
- Implementation costs of the solution concept would be extreme if sinks already present within all patient rooms.

4. Combined Mobile Application

The solution concept generated by the group in this proposal combines aspects of other individual solution concepts relating to the development of a mobile application that performs a variety of functions and allows for a streamlined approach to teach and monitor infection control procedures throughout the hospital for all employees. It would combine the gamification approach previously presented within the individual brainstorming section of this report to inform and teach modules regarding hospital infection control procedures as well as serve as a platform for a monitoring checklist system that requires a mobile verification of the completion of infection control procedural tasks when conducting any medical procedure. This mobile application would serve as a centralized system for not only infection control procedures, but could also be deployed for other teaching modules that all employees must undergo.

Strengths

- Centralized system with intuitive and user-friendly platform.
- Teaches, reminds, and checks infection control procedural guidelines in a centralized system.
- Gamification and rewards within application help incentivize users and hospital employees to properly complete the procedural tasks required of them.

Weaknesses

- Initial implementation of mobile application would be relatively cheap, but upkeep and maintenance of software issues and bugs would be very costly over time.

Group External Research

- UV Light Purification

UV light is a well known method of killing bacteria called ultraviolet germicidal irradiation (UVGI). It is capable of disinfecting air, water and surfaces. According to the National Institute of Health (2010), the primary method of producing this light is through the emission of shortwave radiation (100-280nm) through low pressure Mercury discharge lamps. The emission of this radiation damages the DNA of bacteria and eliminates its ability to replicate. This capability makes it ideal for use in sterilization systems in hospitals as it is able to effectively eliminate bacteria that are transmitted in different vectors and render them harmless. This method is currently used in air disinfection, and is an effective method of sterilization of hospital surfaces [1].

- Copper Surfaces

According to the NIH (2010) Another method to help prevent the spread of bacteria is the use of copper surfaces. Copper has natural antimicrobial properties and helps inhibit growth and is capable of "contact" killing. This is accomplished through bacteria rapidly absorbing copper resulting in cell death. This method is currently being used in hospitals to replace stainless steel surfaces that possess no inherent antimicrobial properties [2].

- Function of a Plumbing Trap

The function of a plumbing trap or a P-trap is to prevent sewer gas from rising up the drain into the house or area that the sink or toilet is. Sewer gas may or may not have an odor, but more importantly it typically contains explosives. The trap is shaped like a U and is filled with a shallow water layer at the base of the "U" to prevent the rising or expansion of the sewer gas. This layer is flushed out and replenished whenever a toilet is flushed or a sink is turned on by forcing the old water out and refilling it with the new water. One issue with current plumbing systems is according to Holinski (2017) pipe climbing bacteria are a potential source of pathogenic bacteria. Bacteria can especially find a home in the U-bend of the sink and can grow and climb up to the actual surface of the sink. This can lead to something designed to improve hygiene to a source of infection. [6,7]

- Mobile Devices for Healthcare Professionals

Although recent, integrating advanced technology into the healthcare system has improved the health outcomes tremendously as it contributes to a simpler and effective way of doing things. Mobile applications are one example that technology made its way to the healthcare environment. According to a piece on Mobile Devices and Apps for Healthcare Professionals: Uses and Benefits by C. Lee Ventola, mobile apps have numerous uses including time management, assessment and monitoring , communication and consulting, educating and training to name a few. This way activities within the hospital environment are accomplished quickly and effectively. It is also mentioned in the piece that the use of technologies like ipads and mobile phones allowed for movable devices that allowed workers to communicate and reach information from wherever they are [3].

- Leadership within Work Environment

The actions of hospital workers directly impacts how hospitals perform. The kind of environment plays a big role on how workers engage with their daily routines and commitment to their task. According to the book on Keeping Patients Safe: Transforming the Work Environment of Nurses, it is discussed that the role of transformational leadership and evidence-based management highly contribute to the overall function of the hospital to guarantee patient safety. Transformational leadership is a strategic process that brings both the leader and follower into a space where they can interact and monitor each other. The piece mentioned that such leadership is often called “el-elevating” or “Inspiring” as it elevates those who follow the rules and actively participate. It is achieved by creating a two-way communication between leaders and followers [4].

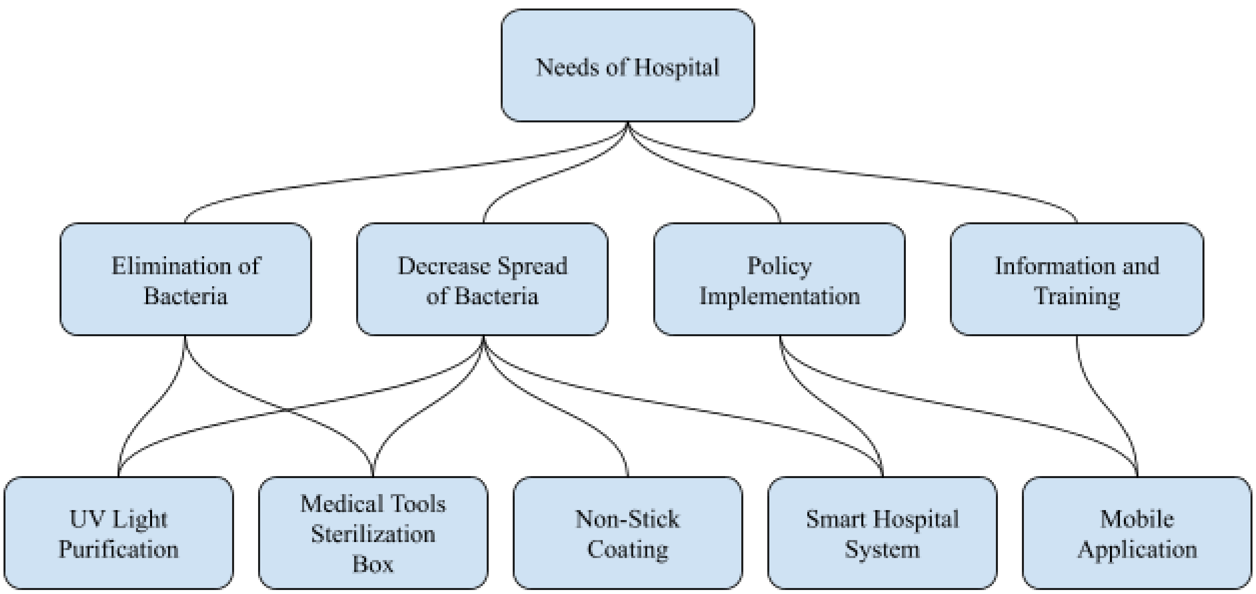
- Patient Education

As stated above, fighting the spread of Hospital Acquired infection requires everyone's effort including patients. In Infection Prevention and You, it is stated that it is important to educate patients about infection control methods, encourage them to ask questions, and voice their concerns during hospital stay. The piece suggested that patients should be aware of Hospital Acquired Infections, know that they can always ask to speak with an infection preventionist, know to clean their hands all often, and know how to monitor the cleanliness of their area [5].
Educate Your Patients. (n.d.). Retrieved from http://professionals.site.apic.org/protect-your-patients/educate-your-patients-on-infection-prevention/.

- Stakeholder Interview with Eve Giannetta

According to Eve Giannetta, manager of infection control at the University of Virginia Hospital, the CDC focuses on 6 main infections for HAI. The two device related infections are central line associated bloodstream infections (CLABSI) and catheter associated urinary tract infection (CAUTI). The other ones include C. difficile, bloodstream infections with MRSA, and surgical site infections. The CDC database only requires two surgical site infections: abdominal hysterectomy and colon surgery. The CDC database only reports ICU and medical, surgical, medical/surgical units. There are coalitions that are focused on decreasing the amount of these infections. For CLABSI, there is an insertion and maintenance coalition. Within insertion, there is an insertion bundle which revolves around a checklist. The biggest issue is that nurses get busy with their own patients and ignore the checklist occasionally. For maintenance, there is standard work developed for nurses. For instance, they need to make sure tubing gets changed in the appropriate time and hub is scrubbed before entering a central line.

Concept Classification Tree (CCT)



Based upon the Concept Classification Tree (CCT) provided immediately above considering the group's five selected solution concepts to consider, analyze, and evaluate, it is clear that each solution concept addresses a variety of needs that the hospital requires when attempting to minimize Hospital Acquired Infections (HAIs). This illustration is particularly insightful because it shows that each solution concept can work on confronting specific and essential issues within hospitals that would minimize the rate of infections spreading within their walls. Another important point when considering each solution concept is that while many of the alternatives vary in scope, they are mutually exclusive and collectively exhaustive as a set, suggesting that all of them could be potentially implemented within hospitals without being detrimental to the implementation of another solution concept. While the group will be choosing one alternative as the final solution concept based upon the decision matrix process and consideration of the product requirements for each alternative to follow, all of the proposed alternatives could be implemented collectively within hospitals that would magnify the effectiveness of the solution in minimizing the rate of which infections spread.

Solution Selection

5 Selected Ideas for Analysis

1. UV light purification of U-bend (plumbing trap) of toilets and sinks
2. Non-Stick Coating
3. Combined Mobile Application
4. Smart Hospital System
5. Medical Equipment and Tools Sterilization Box

5 Product Requirements for Consideration

1. Cost
2. Effectiveness in Reducing Bacteria
3. Usability
4. Installation and Implementation
5. Reliability and Maintenance

Decision Making Process

The process for deciding the primary ideas took place by deciding what the group thought was the most viable solutions. This allowed us to then choose weights for the most important product requirements and weight the values against one another. We chose a scale from 1 - 10 to allow for more variability than a simple 1-5 ranking, with a rating of a 1 indicating a complete inability to deliver on the chosen product requirements and a rating of a 10 indicating a complete ability to deliver on the chosen product requirements for each alternative considered. The group then rated each of the requirements in order of importance and assigned them a weight signifying a relative comparison of significance for each product requirement. These weights were agreed upon by the group as what we thought would be the most important factors in the adoption and use of the chosen product idea. We carefully considered applications, and associated costs with installing and maintaining the product, the ease of use and overall effectiveness. The justification and rationale behind the requirements, metrics, and specifications chosen are necessary considering the extreme importance of each product requirement in its ability to deliver considering the final solution concept would be implemented within a hospital and healthcare setting. The cost requirement and specification must not exceed a certain percentage of the designated budget that the infection control unit possesses and should minimize the cost as much as possible. The effectiveness requirement and specification should ideally reduce 100% of the bacteria present considering the importance that the solution concept performs its desired purpose. Considering these requirements within the decision matrix process, this analysis left a clear final solution concept winner and a couple alternatives tied for the second highest score. The group then performed a sensitivity analysis to further separate out the choices and provide a clearer understanding of how each alternative considered holds up against changing the importance of each product requirement.

Decision Matrix

Decision Matrix	**Cost**	**Effectiveness**	**Usability**	**Implementation**	**Maintenance**	**Score**
Requirement Weights	0.25	0.35	0.15	0.1	0.15	**1.00**
UV Light Purification	-	-	-	-	-	
Ability to Deliver	7	8	10	3	8	
Weight * Ability	1.75	2.8	1.5	0.3	1.2	**7.55**
Non-Stick Coating	-	-	-	-	-	
Ability to Deliver	4	7	8	8	6	
Weight * Ability	1	2.45	1.2	0.8	0.9	**6.35**
Mobile Application	-	-	-	-	-	
Ability to Deliver	9	2	6	7	3	
Weight * Ability	2.25	0.7	0.9	0.7	0.45	**5.00**
Smart Hospital System	-	-	-	-	-	
Ability to Deliver	1	4	9	2	2	
Weight * Ability	0.25	1.4	1.35	0.2	0.3	**3.50**
Medical Tools Sterilization Box	-	-	-	-	-	
Ability to Deliver	5	6	7	9	7	
Weight * Ability	1.25	2.1	1.05	0.9	1.05	**6.35**

Based upon the decision matrix presented immediately above, the UV Light Purification solution concept was ranked the highest based upon the assigned ability to deliver and the weights of each requirement considered. The product requirements of cost and effectiveness in reducing bacteria were strongly considered within the criteria of the decision matrix process as the most essential requirements for the product to deliver upon. The UV Light Purification alternative was not only chosen by the decision matrix, but also chosen by the group to explore in further detail, prototype, and evaluate this solution concept moving forward into the next semester given its feasibility to test and evaluate the requirements put forward for each solution concept present.

Sensitivity Analysis 1

Sensitivity Analysis 1	Cost	Effectiveness	Usability	Implementation	Maintenance	Score
Requirement Weights	0.2	0.2	0.2	0.2	0.2	**1.00**
UV Light Purification	-	-	-	-	-	
Ability to Deliver	7	8	10	3	8	
Weight * Ability	1.4	1.6	2	0.6	1.6	**7.20**
Non-Stick Coating	-	-	-	-	-	
Ability to Deliver	4	7	8	8	6	
Weight * Ability	0.8	1.4	1.6	1.6	1.2	**6.60**
Mobile Application	-	-	-	-	-	
Ability to Deliver	9	2	6	7	3	
Weight * Ability	1.8	0.4	1.2	1.4	0.6	**5.40**
Smart Hospital System	-	-	-	-	-	
Ability to Deliver	1	4	9	2	2	
Weight * Ability	0.2	0.8	1.8	0.4	0.4	**3.60**
Medical Tools Sterilization Box	-	-	-	-	-	
Ability to Deliver	5	6	7	9	7	
Weight * Ability	1	1.2	1.4	1.8	1.4	**6.80**

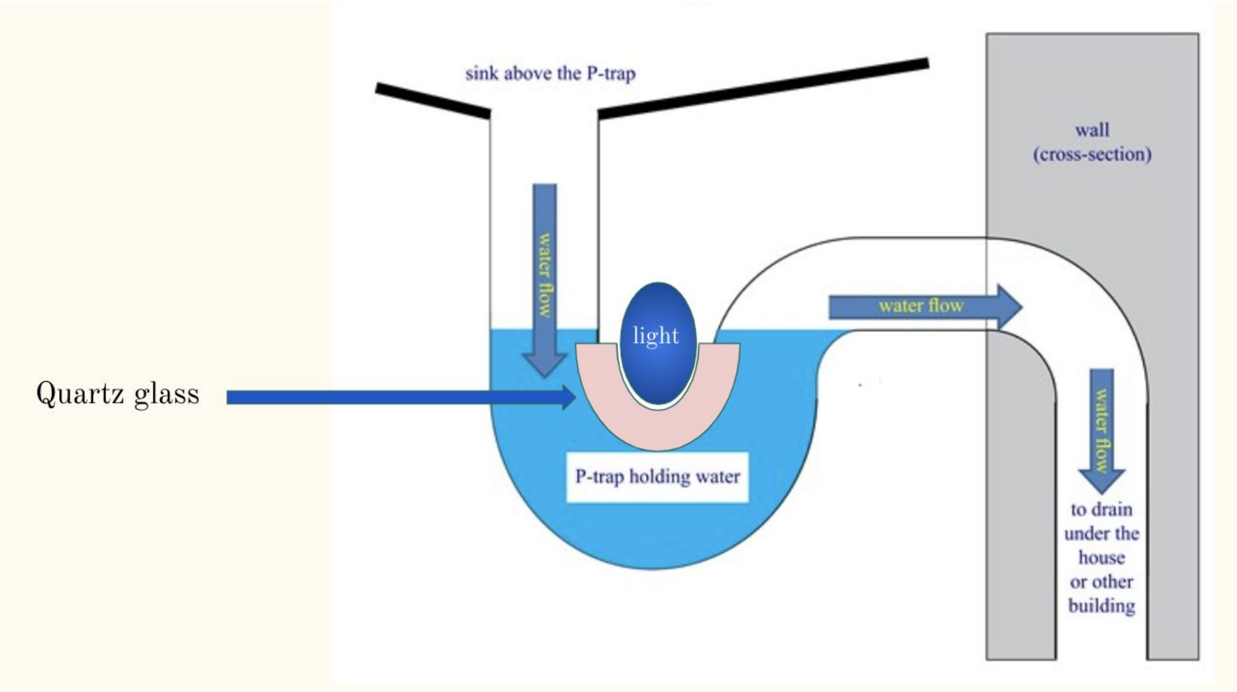
This first sensitivity analysis table considers the weight of each requirement to be equally distributed as each requirement has the same weight. The group chose to analyze the differences in scores for each alternative with all equal weights and compare the desired and selected solution concept from this sensitivity analysis to the selected alternative from the decision matrix. Even with changing the weight of each requirement to be the same and considering each requirement equally, the UV Light Purification solution concept still comes out on top and reaffirms the conclusions drawn from the decision matrix previously discussed. Further analysis of this table shows that with standardized and equal weights, the Medical Tools Sterilization Box solution concept now ranks second behind the chosen UV Light Purification and distinguishes itself from the Non-Stick Coating solution concept where they were previously tied based upon the decision matrix. This sensitivity analysis has provided the team with more insight into a better overall ranking of all the alternatives considered within this analysis.

Sensitivity Analysis 2

Sensitivity Analysis 2	Cost	Effectiveness	Usability	Implementation	Maintenance	Score
Requirement Weights	0.15	0.35	0.1	0.25	0.15	**1.00**
UV Light Purification	-	-	-	-	-	
Ability to Deliver	7	8	10	3	8	
Weight * Ability	1.05	2.8	1	0.75	1.2	**6.80**
Non-Stick Coating	-	-	-	-	-	
Ability to Deliver	4	7	8	8	6	
Weight * Ability	0.6	2.45	0.8	2	0.9	**6.75**
Mobile Application	-	-	-	-	-	
Ability to Deliver	9	2	6	7	3	
Weight * Ability	1.35	0.7	0.6	1.75	0.45	**4.85**
Smart Hospital System	-	-	-	-	-	
Ability to Deliver	1	4	9	2	2	
Weight * Ability	0.15	1.4	0.9	0.5	0.3	**3.25**
Medical Tools Sterilization Box	-	-	-	-	-	
Ability to Deliver	5	6	7	9	7	
Weight * Ability	0.75	2.1	0.7	2.25	1.05	**6.85**

The second sensitivity analysis conducted chooses to more closely examine the implementation product requirement and as a result put less weight on the cost product requirement. The team chose to explore this as a means to examine the feasibility of implementing these chosen alternatives within a hospital setting rather than stress the importance of cost. The rationale behind this decision considers the fact that a hospital should be willing to pay any price to minimize the spread of infections while still implementing a very effective solution concept that is easily installed. While many of the scores for each alternative are very close, the Medical Tools Sterilization Box would be the chosen solution concept based upon the weight of each requirement within this sensitivity analysis. This analysis provides further information regarding possible alternatives to consider other than the UV Light Purification solution concept that was previously selected as the final solution concept to explore.

Final Solution Concept



Depicted directly above is a diagram modeling the UV Light Purification solution concept that was selected as the final solution concept based upon the decision matrix created, the assigned weight of each product requirement, and the sensitivity analysis conducted. The diagram illustrates a typical U-bend plumbing structure within toilets and sinks that the alternative would be implemented within throughout the hospital. A quartz glass piece within this diagram makes up part of the U-bend wall that allows the UV light source present directly above it to radiate through the entirety of the structure and kill the bacteria present that are growing and colonizing within the pipes of the plumbing structure. This design and setup will allow for the UV light to permeate through the pipe system while also not obstructing the flow of water within the system that could detrimentally affect the current design of the U-bend already implemented. This solution concept is an iteration of previous research conducted in minimizing the spread of pathogenic bacteria and infections that originate from the plumbing systems currently used within the hospital. Based upon the analysis and selection of this concept, the team is looking to test and evaluate the product requirements of this UV Light Purification alternative moving forward and confirm our own decision criteria that led us to choose this alternative as our final solution concept.

7 Exploration of Design Concept

Prototyping and Testing

Overview

Having identified a most promising solution concept, our team now seeks to confirm the ability of our concept to satisfy key design requirements. The team intends to explore the true promise of the concept by developing a physical prototype of the solution and using it as the basis for a set of experiments. The experiments are intended to explore the actual ability of the solution concept to address the problem of hospital acquired infections. Following experimentation, results will be analyzed, and the team will recommend future project directions. The team will either present a more detailed engineering description of the design (if the experimental results show promise), or they will present ideas for a revised design that the experiments suggest could be more effective.

The primary goal of establishing the physical prototype was to determine the effectiveness and feasibility of using Ultraviolet C (UVC) radiation to kill bacteria when filtered through quartz glass in the constructed sink-trap system. Producing an exact physical representation of the sink-trap system will allow us to determine the practicality of using UVC radiation to prevent hospital acquired infections arising from sink wastewater that could spread to patients, a group of people who are already at risk.

STEM basis for work

The prototype was grounded in the context of various STEM principles.

Colony counting

Counting bacterial colonies is the main method of data collection for this experiment. Counting colony-forming units (CFUs), a unit that estimates the number of viable cells of microorganism in a sample, requires bacterial culture. Bacterial culture broadly refers to letting bacteria reproduce in a predetermined culture medium (agar in our case) under the standard controlled laboratory conditions that will be specified in the procedure. This microbiological technique is especially important because it is by far the simplest and most accessible method by which we can determine the abundance of bacteria in the sink system, specifically the number of viable organisms. If the number of colonies were to be too numerous to count, then only a fraction (typically a quarter or a sixteenth) of the dish will be examined. If available to us, a click counter and pen will be used to enumerate colony-forming units as shown in the image below:

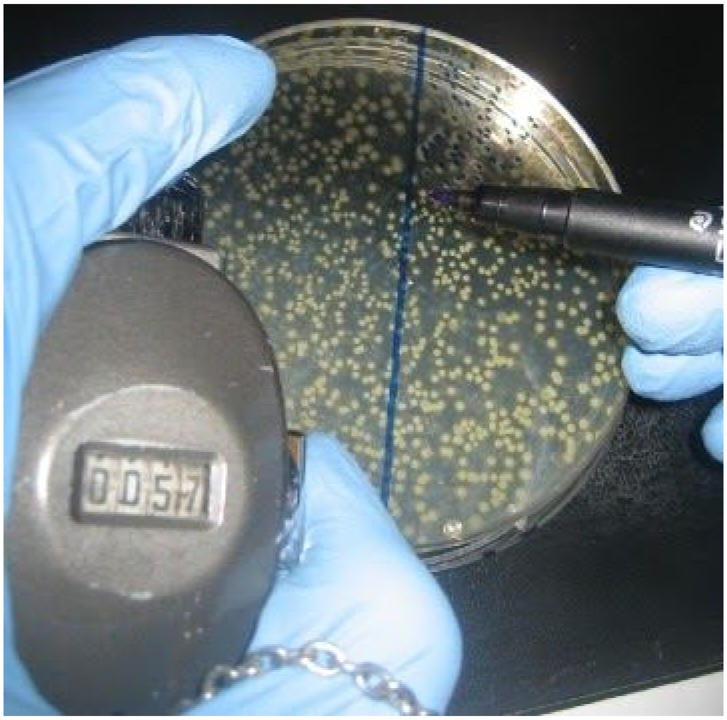


Figure 18: Photo Credit: By Quentin Geissmann - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=28361718

Image processing

If the colonies themselves were too small to count by hand, then there exists software solutions that could have been used to rectify this problem. ImageJ is a image processing program that has the capability to semi-automatically or automatically count the number of objects greater than a certain size and belonging to a certain shape in a frame of view and specifying the scale beforehand allows us to use this program to not only determine the number but also the size of CFUs. Software such as ImageJ minimizes any human error that may arise from counting by hand.

<u>Ultraviolet germicidal irradiation (UVGI)</u>

This experiment depends solely on the efficacy of ultraviolet germicidal irradiation (UVGI). At its core, this method uses short-wavelength ultraviolet radiation (UVC) to either kill or inactivate microorganisms. This is done by destroying nucleic acids and disrupting their DNA, which contains genetic information, and this leaves them unable to perform vital cellular functions. In most cases, the DNA of the affected organism is denatured due to the formation of pyrimidine dimers. Pyrimidines refer to one of the two types of nucleobases in DNA and include cytosine (C) and thymine (T). Such dimers can be seen in the graphic below.

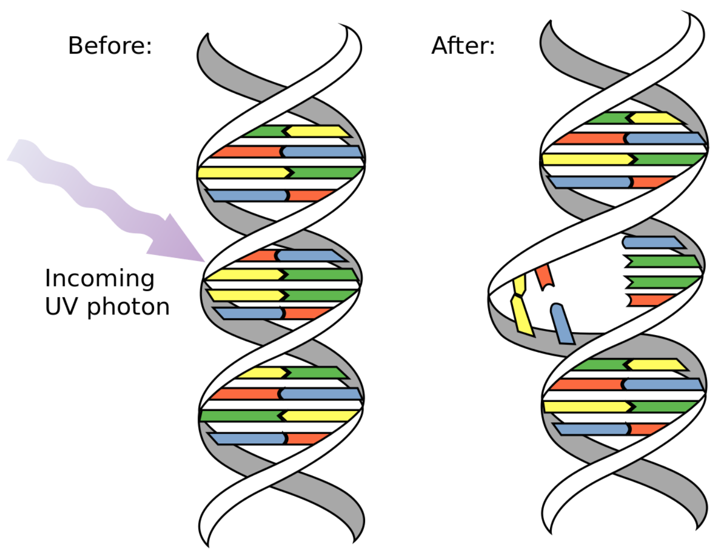


Figure 19: Damage to DNA from Ultraviolet Radiation

In the above image, two adjacent bases bind to each other instead of binding across the ladder and this is what specifically disrupts DNA replication.

<u>Optics</u>

This project is highly dependent on the electromagnetic radiation’s transmission in order to function. The first portion of the experimental procedure is necessary to determine if the lab is conducted with the correct wattage and that the quartz glass is capable of transmitting the proper amount of UV-radiation to sterilize the section that it hits. For the light transmittance we plan to use a UV-C emitting light. UV-C was chosen because it has germicidal properties, however, it has a wavelength between 200 and 280 nm, which is blocked by most glasses. Quartz Glass, however, is often used in spectroscopy because it allows for UV light to pass through unhindered. A rough graph of various cuvette transmittance spectras are pictured below. As depicted, glass and acrylic plastics are unable to be used for our experiments because they are unable to allow enough of the germicidal UV-C light to pass through the lense.

Material	Transmission
Optical Glass	340 - 2,500 nm
UV Quartz	190 - 2,500 nm
IR Quartz	220 - 3,500 nm
Sapphire	250 - 5,000 nm

Table 9: Transmission Wavelengths of Various Materials

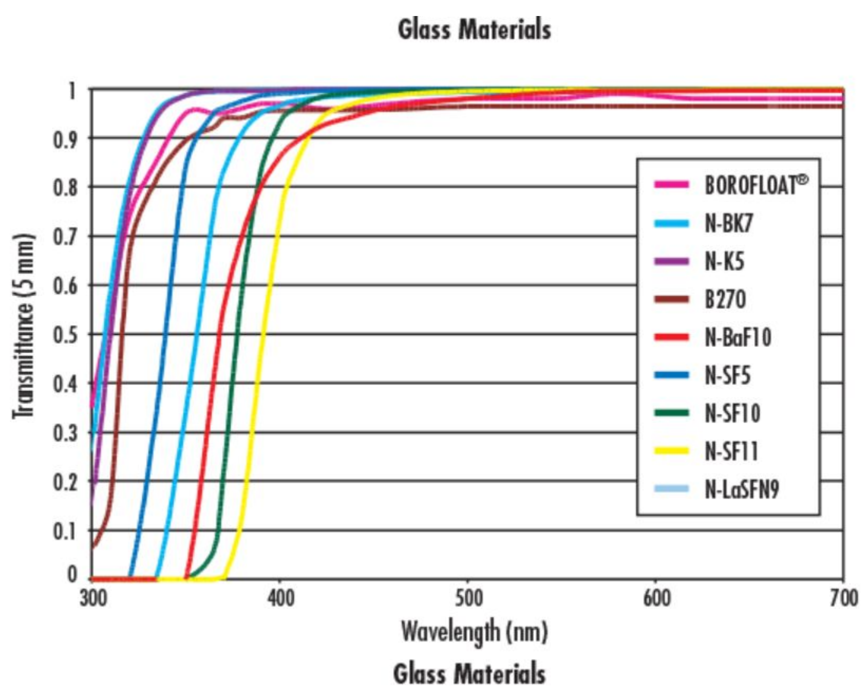
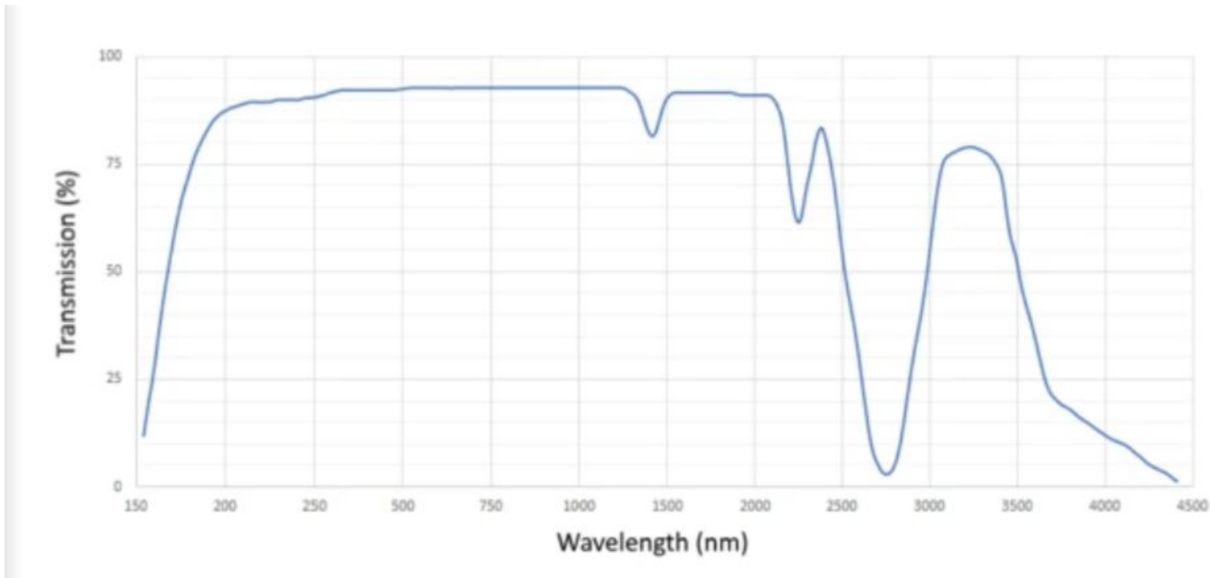


Figure 20: Retrieved From:
https://www.edmundoptics.com/knowledge-center/application-notes/optics/optical-glass/

As pictured above, a vast majority of commercially available glass optic materials only transmit effectively above 350 nm. This poses a significant problem because UV-C has a wavelength between 200 and 280nm which means that the device will not be able to use standard glass lenses to transmit the germicidal light to the U-bend. A solution to this issue is the use of quartz optical glass. Pictured below is the transmission graph of a quartz cuvette.



Transmission through UV quartz glass between 150 nm and 4500 nm.

Figure 21: UV Quartz Glass Transmission Spectrum

Pictured above is a more detailed Transmittance spectra of quartz glass. As shown above quartz transmits over 80% of all light making it ideal for the use of our lense into the U Bend. Accounting for this slight loss of 20%-15% of the germicidal rays still allows us to effectively expose the bacteria to the UV-C light. Another important point to consider is that standard absorbance/transmittance measurements are calculated with 1cm thick material, indicating that less will be absorbed provided we used a thinner pane of quartz glass. A second key portion to consider is the absorbance of water, water has a unique absorption spectrum, however, UV-C light that is closer to 280nm transmits quite well. The success of the UV-C light as a sterilization method is seen in water purifiers for backpacking that utilize UV-C light.

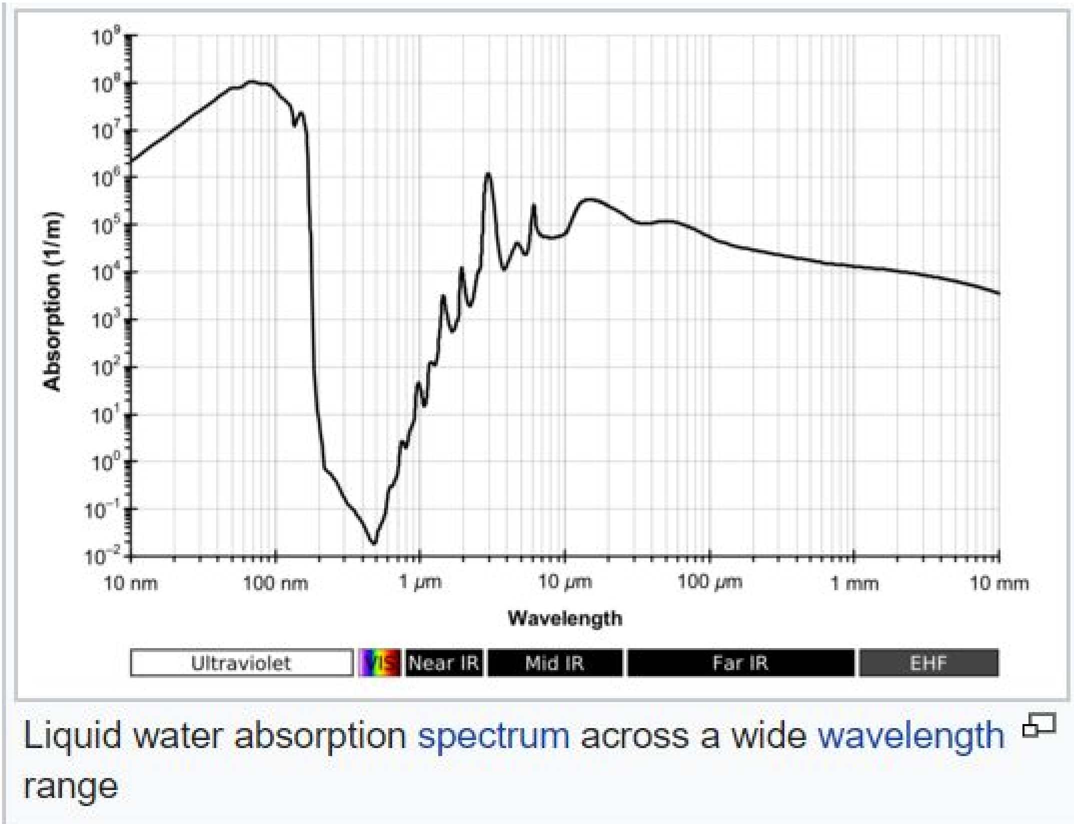


Figure 22: Liquid Water Absorption Spectrum, Retrieved From:
https://en.wikipedia.org/wiki/Electromagnetic_absorption_by_water

Statistical concepts used for data development

Performing statistical analysis on the numbers of CFUs can help in the presentation and interpretation of these data. Descriptive statistics will most certainly be performed to determine measures of central tendency, range, and spread of the data set as these values are essential to any experiment. Inferential statistics may also be useful in that it allows us to still make conclusions from data that may have been subject to random variation in the form of sampling variation due to the inability to count all CFUs or observation error due to misidentifying a CFU. Basic statistical hypothesis testing techniques such as Student's *t*-test may prove useful.

Prototyping summary

The physical prototyping was split into two main stages: the manufacture/assembly of the physical prototype and two the testing of the physical prototype. The manufacture and assembly can be completed without the usage of highly specialized equipment as all necessary parts can be purchased, 3D printed, or borrowed from the university. Details of the manufacture / assembly and purchase components are listed below, specifically in the form of graphics and procedure. As stated above, effectiveness will be measured by the percent elimination of bacteria using the cell culture methods that will be detailed in the following sections. The immediately following section provides an overview of how the physical prototype construction.

Table 10: Supply List and Explanation

Parts	Source/Best Place to Buy
Sink Basin	Commercially Available from Hardware Stores (Can be Obtained at Home Depot or Lowes)
U-bend Connector	Commercially Available from Hardware Stores
UV-C Light	Baiwei Lighting (ASIN: B07YCM12XV)
Quartz Glass	Alpha Nanotech Inc. Part No. QPX0015X8A19
Teflon Tape	Commercially Available from Hardware Stores
Pipe Connectors	Commercially Available from Hardware Stores
Box/Cover	Commercially Available from Hardware Stores
Socket + Power Chord	Commercially Available from Hardware Stores
Pipe Cutter	Commercially Available from Hardware Stores
Electric Hacksaw	Commercially Available from Hardware Stores

Glass Cutter	Commercially Available from Hardware Stores
Waterproof Sealant/Adhesive	Commercially Available from Hardware Stores
E. Coli K-12 Strain	Carolina Biological Item # 155068
Bacillus Subtilis	Carolina Biological Item # 154921
Liquid Culture Vials	Carolina Biological Item # 715060
Petri Dishes	Carolina Biological Item # 740996
Agar Solution Supplies	Carolina Biological Item # 821045
Gram Staining Supplies	Carolina Biological Item # 319570
Personal Protective Equipment (Gloves, Goggles, & Coat)	Borrowed from University or Purchased at University Bookstore
Cleaning Supplies (Cavicide, Bleach, & Autoclaves)	Borrowed from University

<u>Part descriptions</u>

- The first optional piece for this experiment is a sink basin, which will provide an additional level of structure to enable the device to more accurately represent the device how it is intended to be used. This piece is not completely necessary for testing, but provides a better image of how the device works in a system.

- The base for this device is the U-Bend Connector, this provides the underlying structure of the device. A plastic PVC pipe is preferred due to the ease that it can be modified and cut.

Figure 23: PVC Pipe

- UV-C lights; the UV-C light provides the electromagnetic radiation that is necessary to kill bacteria. The device will be built around the UV-C light and will allow for the light to pass through the window cut into the pipe. The picture represents a form of UV-C light in order to provide a visual representation.

Figure 24: UV-C Emitting Light

- Quartz Glass: This will provide the opening that allows for the UV-C light to pass into the U-bend and will be fixed into the plastic structure of the PVC pipe. For this to function the glass needs to be a thin pane, and small enough to be embedded into the pipe.

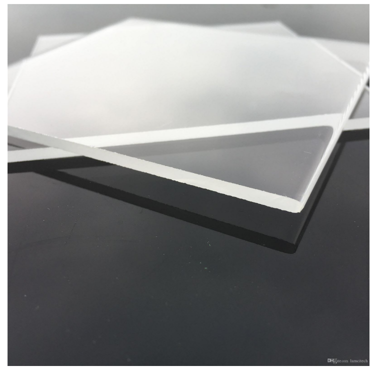


Figure 25: Quartz Glass Pane

- For this structure a sealant is required in order to fix the glass to the structure and seal the box that guards against UV light emission. For the testing portion Teflon tape is optimal until we can create a more permanent fixture.
- Connectors for pipes are also required in order to integrate our structure into the sink itself and refasten a new U-bend.
- Another important material that is needed is the Black Box/ Cover to seal outside from harmful UV-C rays. For the proof of concept we will Utilize opaque plastic sheets and teflon tape to create a sealed structure
- Another key piece of the structure is a socket and power cord allowing for the

<u>Tool descriptions</u>

- A pipe cutter is greatly helpful in the construction of the device, it allows for clean cuts of the pipe and allows for effective modification regardless of the pipe's material.
- An electric hacksaw is also necessary to provide the ability to make clean cuts in the metal and to allow for the ability to create a hole for the quartz glass to be placed in.
- A glass cutter is also essential to cut the glass to a precise shape in order to ensure a proper fit.
- A flexible waterproof adhesive is necessary to construct the model and ensure that the pipe remains sealed and the device remains fixed.

<u>Bacterial culture materials</u>

The key requirements for the species of bacteria chosen is that they grow well in lab settings and are representative of all bacteria.

- One of the key bacteria is *Escherichia coli*, specifically the K-12 Strain, in order to be non-pathogenic and to represent gram negative bacteria. This bacteria needs to be a live specimen so that it can be used for the tests.
- *Bacillus subtilis* will be used to represent the Gram-positive bacteria due to its Biosafety level one rating and its non-pathogenic nature. Again the bacterial sample needs to be a living sample so that it can be cultured for tests.
- For the second portion of the procedure vials are needed to grow the liquid cultures.
- Petri Dishes are also necessary to grow the solid cultures of bacteria to test the success of the sterilization process.
- Another key type of supplies that is needed for the testing portion of the procedure is Gram staining chemicals and implements.
    - Crystal Violet is necessary for the initial colorization step in the Gram Staining Process; it accounts for the Gram Positive bacteria's distinctive purple color.
    - Safranin is necessary for the final step of the Gram staining process and gives Gram Negative bacteria the distinctive pink coloration.
    - Iodine is necessary in the Gram Staining Process in order to fix the crystal violet dye in the Gram Positive bacteria to prevent the decolorization by the Acetone.
    - Acetone is necessary to decolorize the Gram Negative bacteria and wash off the crystal violet dye, this allows for the clear differentiation between the Gram Negative and Gram Positive bacteria.
    - Slides are used to observe the bacteria under the microscope and assess the bacteria cultured.
    - A microscope is necessary for the examination of the slides.
- An Incubation Chamber is necessary in order to grow the bacteria.
- Sanitization Equipment is necessary to clean up lab spaces.
    - Bleach Water Mix or clorox wipes can be utilized to sterilize surfaces.

Personal protective equipment

Protective Gear is also necessary for the operation of the device and to conduct the biological experiments.

- Nitrile/Latex Gloves
- Eye Protection - bacteria rated goggles
- Lab Coat for Splash Protection

Specific experimental procedure description

Our physical prototyping procedure was built around two parts. The first main part was to ensure that the light effectively functions at killing bacteria both alone and when filtered through the quartz glass. The second major test is determining how well it functions in the completed system where we test its effectiveness in the enclosed system.

Procedure Part I Initial Test - Solid Cultures Proof of Concept

1. Obtain petri dishes and prepare an agar solution to provide nutrients for the bacteria.
2. Inoculate 3 dishes with the *E. coli*, and 3 dishes with Bacillus Subtillus.
3. Divide into 3 groups with one of each type of bacteria petri dish Control, UV-Radiated, and UV-Radiated with Quartz Glass
    a. Leave the Control group alone, allow it to grow in the incubator unhindered. This is necessary to compare initial growth
    b. Expose the second group to UV radiation for 25 minutes
        i. To accomplish this leave the top open in the petri dish and conduct radiation procedure with safety goggles on and in a designated space to avoid eye and skin damage
    c. Repeat Part b with a pane of Quartz glass in-between the light and the petri dish
4. Allow for growth in the incubation chamber for 48 hours at 35 degrees Celsius
5. Compare and Assess the Growth of each of the Petri Dishes with a Gram-Staining Process
    a. Note E Coli is Gram Negative and Bacillus Subtilis is Gram Positive

Notes About this Procedure:

This procedure is designed to test the effectiveness of the UV-C light at effectively preventing the growth of bacteria. Though this test is to measure the effectiveness of the set-up, it is a proof of concept, simply to determine that the idea is viable and works in practice.There is three separate classifications for each bacteria; the control is so we have something to compare our results to, there is one that works with the just the germicidal UV-C light, and the third one has both the quartz glass and the UV-C light so that we can determine if the quartz glass has an adverse effect on growth. This procedure requires an incubator that can be set to 35 degrees because that will allow both the E. Coli and the Bacillus Subtillus to grow simultaneously in the incubator. Though it is not necessary to grow them both in the same incubator, it significantly reduces the gear requirements to conduct the experiments as incubators are expensive. From this experiment, we will be able to determine how effective the light was based on the growth amounts of the bacteria. In order to ensure that reliable results are recorded, conduct this experiment multiple times and multiple samples can be taken from each petri dish. This will allow us to conduct a statistical analysis on the samples to determine how successful the sterilization procedure was.

Gram staining

The Gram Staining procedure is a standardized process that is included below. The rationale behind different steps is explained beneath the process, and the explanation of the materials used is indicated in the supply section.

Gram Staining Procedure

Retrieved from Michigan State University, URL:
http://learn.chm.msu.edu/vibl/content/gramstain/module_instructions.pdf

Module: **The Gram Stain**

Procedure - click "start lab"

From a liquid culture, take a loopful of bacteria emulsify it in a small drop of water or saline on the slide. This should be a thin, not milky, suspension or it will not stain properly. Air dry the slide. *This is done automatically in the virtual module.*

To begin:

1. Heat fix the slide: click on the Bunsen burner, pass the slide gently two or three times (1-2 seconds) through the flame. Do not overheat - this will cause distortion of the cells.
2. Flood the slide with crystal violet for 1 minute
3. Rinse with H_20
4. Flood the slide with iodine for 1 minute
5. Rinse with H_20
6. Decolorize with alcohol for 5-10 seconds
7. Rinse with H_20
8. Flood the slide with safranin for 1 minute
9. Rinse with H_20
10. View slide under the microscope

The "slide" contains *E. coli* and *Staph. aureus* – is that what you see?
If not, think about what you might have done incorrectly
Then, repeat the exercise.

When you are finished with the exercise, click on "Examine Examples" to see actual micrographs of several bacteria that have been gram stained. You will recognize the names of many of the bacteria from lecture.

Some Pitfalls:

1. Slide not heat-fixed: smear will wash off → what would you expect to see?
2. Slide over heat-fixed: cellular morphology may be distorted
3. Slide over-decolorized: gram-positive bacteria will appear gram-negative
4. Slide under-decolorized: gram-negative bacteria will appear gram-positive
5. Smear too thick: cells in very thick areas will not decolorize properly and gram negative bacteria will appear gram-positive
6. Insufficient time for safranin counterstain: gram-negative bacteria may be very faint and difficult to see

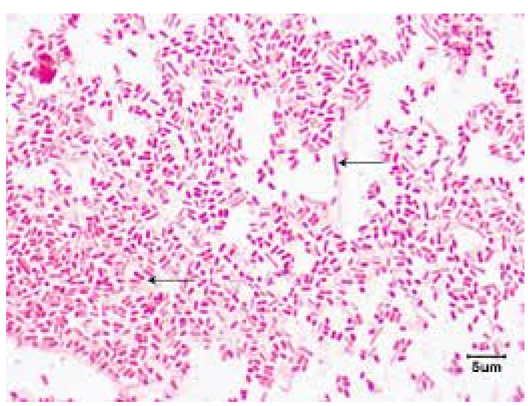


Figure 26: Expected Gram Stain Results for E. Coli Retrieved From: http://faculty.ccbcmd.edu/courses/bio141/labmanua/lab1/gnrod.html

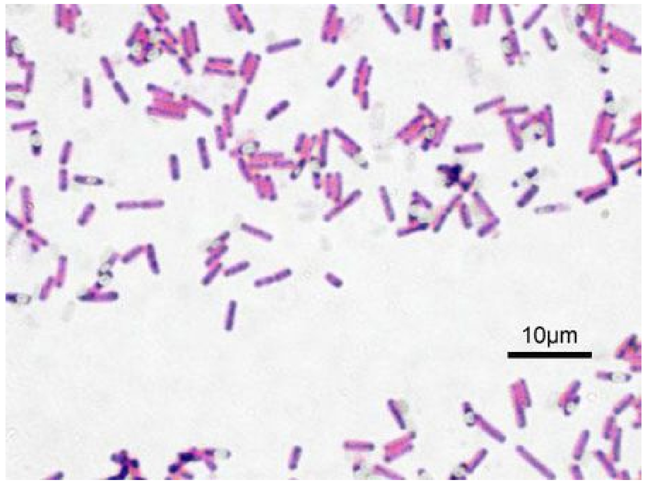


Figure 27: Expected Result of Gram Stain Bacillus Subtillus Retrieved From: http://soft-matter.seas.harvard.edu/index.php/Bacillus_subtilis_spreads_by_surfing_on_waves_of_surfactant

This procedure was obtained from Michigan State University's Gram Staining Module. Gram staining is a standardized procedure that was developed in 1884 by Hans Christian Gram (National Institute of Health 2019) to make bacteria more visible and is capable of differentiating between different cell walls of bacteria classifying them into Gram Positive bacteria and Gram Negative bacteria. According to the National Institute of Health (2019) Gram Negative Bacteria are characterized by a thick peptidoglycan cell wall while Gram Negative Bacteria have an outer membrane with a thinner peptidoglycan layer underneath the outer membrane. This structure allows for the gram negative to absorb the crystal violet and maintain a purple color, this color is fixed with the Iodine treatment which prevents its decolorization. The gram negative bacteria's exterior also turns purple with the crystal violet, but the iodine does not fix the color in the exterior membrane and it subsequently loses the purple coloration with the decolorization. The Gram Negative bacteria takes in the Safranin dye and turns a pinkish color. This process will allow us to easily see the bacteria under a microscope and will enable us to see if there is any cross contamination between samples. For this experiment the Gram Positive Bacteria is the *Bacillus Subtilis* and the Gram Negative Bacteria is *Escherichia Coli*. The purpose of conducting a gram stain is to help visualize the bacteria grown and to double check that no cross contamination occurred. This is especially important in later experiments due to the fact that they will be utilizing the device to contain the bacteria and we want to be sure that there is no residual bacteria build up.

Specific Computational Description

The goal of the computational simulation procedure is to convert the tests conducted into a quantitative analysis. The initial procedure is proof of concept, and is simply there for a qualitative yes no answer, however, in order to convert it to a more careful analysis, there are several steps to take. This provides the method for analyzing bacterial growth, and provides instructions for how to best analyze and visualize the data.

Instructions for Quantitative analysis of colonies

1. Conduct this test 3 times, to allow for a calculation of the accuracy of our prediction.
2. Within the Petri dish, count the number of colonies to compare each sample.
    a. Note it is important to use the same inoculation pattern for each sample in order to get a an accurate comparison
    b. This method allows for us to count many data points without growing a large number of samples.
    c. To accurately count the number of bacteria set up a grid system and count the number of colonies per block
3. Once this is complete create a scatterplot for the aggregate number of colonies for each method.
4. To compare the amount for each method conduct a linear regression analysis for time in UV light vs number of colonies
    a. There should be 6 separate graphs
        i. Two per bacteria for the first procedure, one set accounting for no quartz glass and another set for the experiment with quartz glass

There should be one graph for each type of bacteria for the second procedure, that correlates radiation time to the number of colonies counted on the petri dish.

5. From the analysis calculate the effectiveness of the device at reducing the amount of bacteria after use.
    a. From this data one should be able to determine the optimum amount of time that the UV-C light should run, or even if it is a viable solution
6. Further, the experiment can be repeated multiple times to generate an empirical distribution of bacteria colony data from the methods of experimentation. These data points provided by the outcome of the experiment allow for more robust statistical modeling and testing including tests of significance and creating summary.

Note: For this process a statistical analysis can be best conducted using statistical packages within SAS or MATLAB that are both capable of forming accurate and customizable graphs for our data.

Description

This procedure is designed to measure the effectiveness of the device in a more realistic setting. This design uses functions by first growing both the E Coli and the Bacillus Subtilis bacteria in a liquid culture. Each liquid culture will then be mixed with water and allowed to sit in the U-bend device we created in order to allow the UV-light to sterilize the pipe while the UV light is turned on for 25min. The solution will then have a sample taken from which will then be inoculated into a petri dish filled with the auger solution. Similar to the first procedure the sample will then be allowed to incubate for 48 hours at 35 degrees celcius to analyze the effectiveness of the sterilization procedure. This process can be repeated with the light set at different amounts of time to analyze how much time is necessary for the sterilization process.

Procedure for official U-bend Effectiveness Test (Adapted from Kotay et al.)

1. A U-bend connector made of polyvinyl chloride (PVC) with the specifications specified in the supply list above will be purchased
    a. If the dimensions are later deemed unsatisfactory (too large), then a pipe cutter will be used to modify them
    b. If the pipe size cannot be physically modified, then larger or smaller connectors will be purchased accordingly
2. UV-C bulbs will be purchased and fixed at the bottommost point of the U-bend
3. Quartz glass according to the specifications above will be fixed into the plastic structure of the PVC pipe to provide the opening that allows for the UV-C light to pass into the U-bend
4. The P-trap system will be constructed by attaching corresponding pipes to the U-bend connector and a drainage source will be established to be used as necessary
5. All potential leaks will be sealed using Teflon tape as a sealant
6. The system will be sterilized using bleach to prevent contamination from outside sources immediately before the bacteria is introduced to the system
7. A cover will be oriented such that the outside of the system is sealed from harmful UV-C rays
8. A non-pathogenic strain of the bacteria, *Escherichia coli,* will be grown in vials and incubated in parallel to the previous steps
9. A single isolated colony of *E. coli* will be inoculated in a 5 ml tryptic soy broth (TSB) that will be created following the instructions in the Bacteriological Analytical Manual (Center for Food Safety and Applied Nutrition, 2017)
10. To establish the *E. coli* in the sink P-trap, fill the P-trap with a solution of100 ml x 0.1 TSB and inoculated at a density of 10^3 CFU/ml
11. After inoculation, both ends of the P-traps will be covered with perforated Parafilm and be incubated at room temperature for 14 days to facilitate sufficient growth
12. After the P-trap was installed, 25 ml of TSB followed by 25 ml of saline solution will be added in a 1:3 ratio to mimic the nutrient exposure in a hospital

13. The medium in the P-trap must be replaced with fresh 0.1 x TSB every 48 h
14. An aliquot of medium and a swab sample from the inner surface of the P-trap will be plated on tryptic soy agar plates to monitor the growth of *E. coli* in the P-traps
15. The plates will be incubated overnight at 37°C, and CFU will be enumerated either by hand or using ImageJ as the situation requires
16. The culturing of *E. coli* will take place in a room separate from the sink gallery to avoid contamination.
17. The inside of the trap that is closer to the input will be swabbed to see if a biofilm containing the E. coli has extended upward
    a. This will be done by drilling sampling ports along the length of the P-trap and fitting them with silicone stoppers
    b. Sterile cotton swabs that are pre soaked in saline will be inserted through these sampling ports, and samples were collected by turning the swab in a circular motion on the inner surface
    c. Sample swabs will be "pulse-vortexed in 3 ml saline, and serial dilutions were plated"
18. If the p-trap system used in the first experiment is reusable, then it will also be sterilized for use with the second bacteria, *Bacillus subtilis*
    a. If it is not, then an exact copy of the system will be created
19. Steps 7-16 will be repeated with *B. subtilis*
20. All materials and agents used in this experiment will be disposed of using the following biosafety level 1 guidelines taken and adapted from UCSD
    a. "Liquids: Add bleach to liquid waste to a final concentration of 10% bleach. Let sit for 30 minutes, then dispose down the sink"
    b. "Vacuum flask: Add bleach to vacuum flask before aspirating liquid waste. Final concentration should be 10% bleach"
    c. "Solids: Dispose of solid waste in double red biohazard bags both labeled with address, that are held in rigid, covered containers with biohazard labels. Transport

to biohazard collection area in a closed rigid container for final disposal" by UVA EHS

d. "Surface Decontamination: Use 10% household bleach solution or other appropriate surface disinfectant. Allow 5 minutes of contact time before wiping area"

Prototype, testing & results analysis and presentation

Due to the COVID-19 pandemic and its repercussions, we were unable to construct a physical prototype and test its effectiveness. The physical prototype is based on the design drawings detailed in the following sections.

Safety & Lab Space Approval

Prior to starting this project, we had to undergo biosafety training and get approval for lab space. The agents with which we worked are considered biosafety level-1 (BSL-1) materials. Before working with any BSL-1 biological materials, each group member had to complete a basic biosafety online training module that was administered by UVA Environmental Health & Safety. This module can be found at https://ehs.virginia.edu/Biosafety-Training.html and stressed concepts such as proper and improper lab practices and discussed the decontamination of potentially infectious materials before disposal using bleach or isopropanol. Personal protective equipment (PPE) is relaxed at this level as the only required labwear was goggles, nitrile gloves, and lab coats. After this training was completed, our capstone advisor submitted our project proposal to the UVA Institutional Biosafety Committee (IBC). The IBC does not reject BSL-1 projects but did provide recommendations and asked for clarifications about aspects of our experiment. Our capstone advisor also helped us secure an isolated space in which we could construct our prototype and conduct experiments. This space was on the ground floor of Thornton A-Hall.

8 A Design in Detail

A Description of the Selected Concept

The key concept behind the use of the UV-C Radiation in the U-bend of the sink is the elimination of the pipe climbing bacteria before they can reach the point that will infect patients and this will be illustrated in the following section below. The U-bend of the pipe provides an excellent place for the pipe climbing bacteria to live due to the fact that it always contains water, and sediment and other particles can settle at the bottom.

One key factor in our design is the use of the UV-C light on the outside, rather than the inside of the device. This provides an easy method to change the bulbs without having to reach into the sink or disassemble the sink plumbing. This also provides the added advantage that the UV-C emitting device does not have to fit in the u-bend, making cheaper, more commercially available bulbs a viable option. The idea of using the UV-C light on the outside also does not restrict water flow, and makes the use of waterproof electronic designs unnecessary.

The use of an exterior bulb does cause several new engineering design challenges. First, and most importantly, it needs to be able to shine the germicidal radiation on the actual contents to have any effect. This ability is limited by the fact that most u-bends are opaque and glass and plastics, though transparent in visible light do not transmit UV-C light. This necessitated the implementation of either a U-bend made out of a material that can transmit the light, or a "window" of some sort to allow the light to be projected into the U-bend. Based on these requirements, two materials fit the optical needs of the design, synthetic sapphire lense and quartz glass. Sapphire, though effective, was found to be less optimal than a quartz glass lense. This was decided for two main reasons, first quartz glass is cheaper and more accessible, and second quartz glass provides a better medium for transmission of the UV-C light.

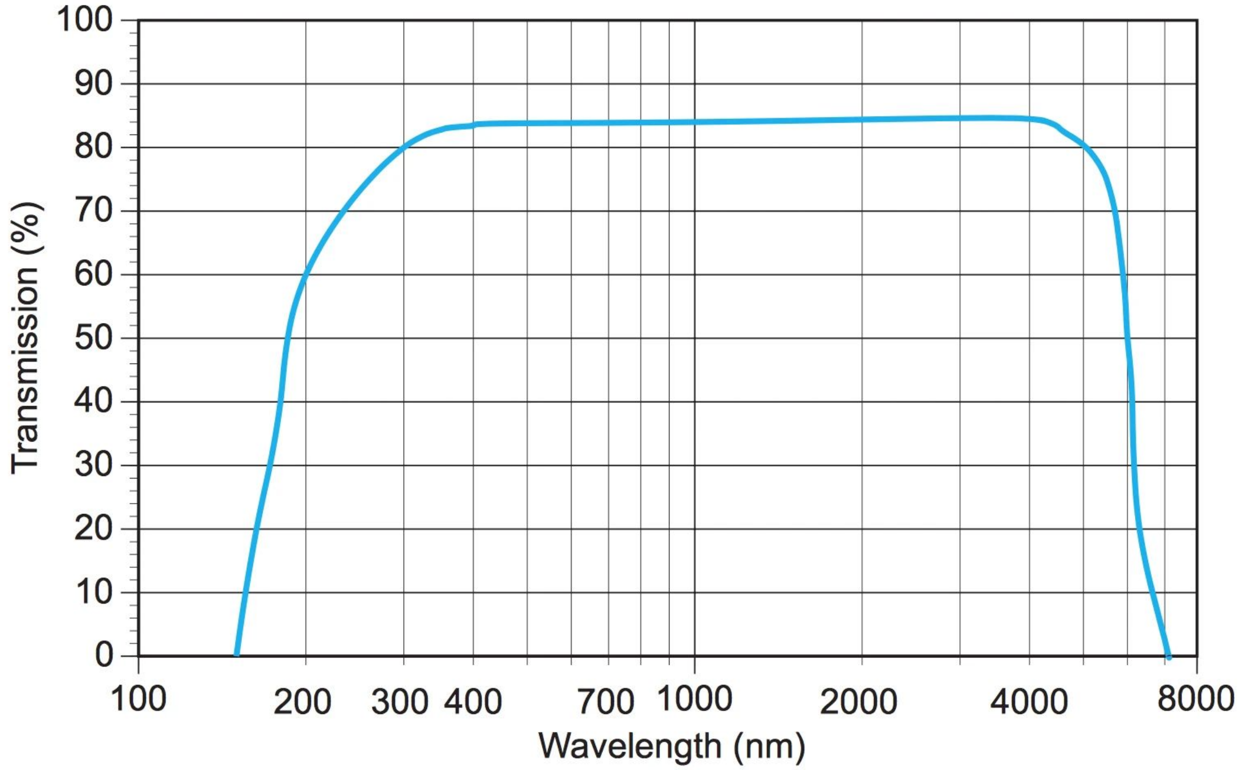


Figure 28: Synthetic Sapphire Emission Spectrum

A second main concern faced by having an exterior UV-C emitting light bulb is human exposure to the radiation. The light emitted is a high-energy low wavelength UVlight, normally most humans will mostly face UV-A and UV-B light which are lower energy and longer wavelength. This relationship is governed by Planck's equation:

$$E = hv = hc/\lambda$$

where h is Planck's constant, c is the speed of light in m/s, λ is the wavelength, and *v* is the frequency in Hz. The high energy electromagnetic radiation from UV light can cause burns and cell damage, the UV-C specific wavelengths are much more harmful and can also lead to blindness. This complication has led to the necessity of a design that seals the light from the outside to prevent accidental exposure, the way our design accomplishes this is by simply containing the device in an opaque box. This simple solution provides a relatively cheap alternative to finding an effective filter or painting over sections to avoid light from leaking out. The lack of materials that effectively transmit the UV-C light enables a flexible range of materials to be used. This box must be sealed to prevent the exposure to the light and to prevent Ozone produced from escaping.

This design also faces the challenge of being compact enough to fit underneath most sinks and the capability of being nested into the U-bend of most sinks. This necessitates for the space of the device to be utilized well, and sets a rough size limit on our device.

Another key design consideration that this project was the price considerations of our application and product. In order for this device to be utilized, it needed to be affordable for hospitals and easy to maintain. This device achieves this by being relatively inexpensive to produce, material costs for this project are estimated to be just under $150, and relatively cheap to maintain. Routinely the lightbulb will need to be replaced and the quartz glass interior of the pipe will need to be cleaned. Several observational studies still need to be conducted to establish guidelines on the time between cleanings and lightbulb changes, however this will require an analysis of sediment buildup and device lifespan.

Design as an Embodiment of Requirements

Based on the assigned weight of each product requirement in the decision matrix created and the sensitivity analyses conducted in the Generate and Select report, UV light purification was chosen because of its strong scores in cost and effectiveness. With regards to cost, the most essential requirements we mandated was minimization of the number of additional personnel to manage new systems and staying with the hospital's allocated funds to fight HAI. The acceptable and ideal requirements for these were 1-2 people per hospital and no additional personnel and 50% and 30% of the hospital's allocated funds to fight HAI respectively. Our group of 3 aimed to construct a successful prototype with a maximum budget of $400. With regards to effectiveness, the most essential requirement we mandated was elimination of bacteria in the wastewater. The acceptable and ideal requirements for this was 85% elimination and 100% elimination respectively. UVC radiation is known to kill bacteria in standard settings such as the purification of food and drinking water but the discrepancy between the acceptable and ideal lies in the fact that it is unsure how effective our prototype will be given that UV radiation is being used in a novel way. This percent elimination can be quantified by culturing bacteria swabbed from the interior of the sink-trap input at the intervals specified in the procedure and calculating the percent decrease. The cost-effectiveness of the solution concept was prioritized because a solution that is productive in relation to its cost is more likely to be adopted by hospitals.

Solution Concept Diagrams

With regard to the design of the implementable solution, methodology will be followed from previous descriptions of assembly. Included within this section are two-dimensional and three-dimensional viewpoint renditions of the U-bend structure as used within the group's solution concept.

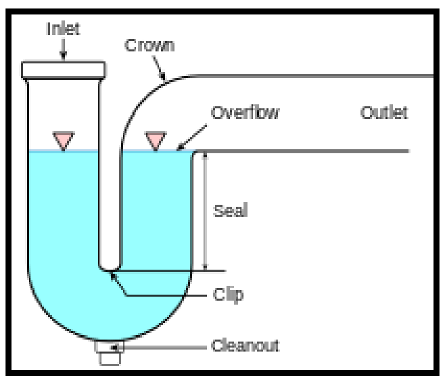


Figure 29: Component Overview U-Bend System

Figure 27, located directly above, visualizes a basic U-bend structure setup labeled with common included parts and features within a functioning U-bend. A focus of this figure is the cleanout system embedded into the bottom of the U-bend that allows regular draining and cleaning of the U-bend system from the base of the structure. This cleanout system provided inspiration for the solution concept proposed by the group, in which the UV light irradiation device will be instead introduced to the U-bend system substituting the cleanout system within this figure.

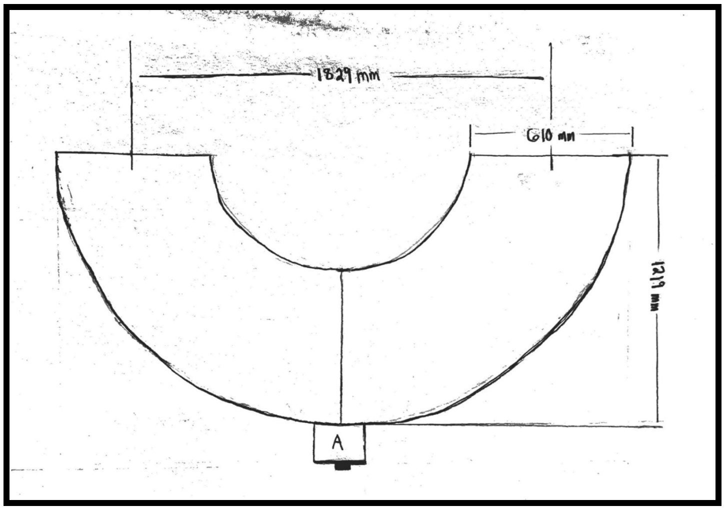


Figure 30: Dimensional Layout of U-Bend System

Provided above within Figure 28 are the dimensions set for the construction of the U-bend system given standardized and industry certified measurements for the proper structural integrity of the U-bend given its curvature. This is essential to emphasize within the construction of the system because it allows for proper demonstration of industry and STEM requirements as well as for the replication of the experiment from other parties by specifying the dimensions of the U-bend being used within the experiment.

1. Quartz Glass Plane
2. UV Light
3. Body Capsule
4. End Cap

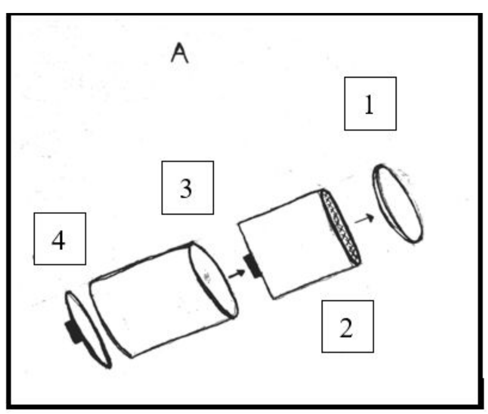


Figure 31: Close-Up Breakdown of Solution Concept

Figure 29, directly above, illustrates a broken down viewpoint of the constructed device containing the UV light and the quartz glass put in place at the bottom of the constructed U-bend. The labels provided indicate the respective parts of the design, and all individual parts shown will be encapsulated within the device before integrating it into the bottom of the U-bend to begin experimentation and irradiation of the bacteria grown.

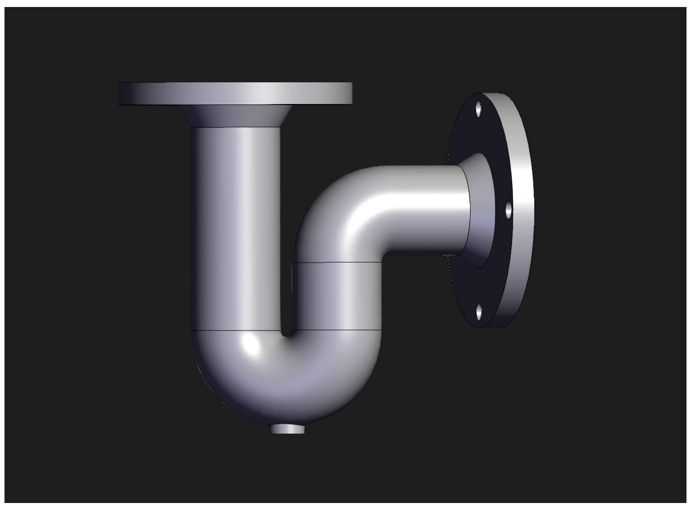


Figure 32: Integrated System Design 3D Model

Further, a three-dimensional concept design of the solution, Figure 30, is provided directly above rendered within AutoCAD inventor for the purpose of visualizing the system as a whole based upon the specified dimensions and components of the design.

9 Reflection on Design

Alexander Knoop

An Assessment of Design Viability: From the laid out processes that we have developed and the research conducted, I believe that we have a potentially viable solution. Unfortunately no tests were able to be conducted on our product due to unforeseen circumstances, this leaves us in a position where our group is unable to definitively measure the effectiveness of the device. This creates a situation where we can only make inferences of what potential weaknesses might have been, and use our best judgement to suggest improvements. The lack of testing also leaves the problem where there are no results to analyze or discuss.

Recommendations: I do however believe that it will face some issues that when resolved could significantly increase the design's effectiveness or the lifespan. The first is to ensure that the window placement is optimal to cover the most area in the u-bend as possible. I think this could be adequately accomplished by utilizing a glass U-bend to find what covers the most area. Another key feature that would improve this structure is the ability for it to automatically clean the glass. However, I think that one key strength of the design is its simplicity, there are very few moving parts and few points of failure. This enables relatively few repairs and fairly simple maintenance. This simplicity also is a strength in the manufacturing process, this allows for a cheaper construction and shorter manufacturing times during the production phase of the product life cycle.

Rex Focht

An Assessment of Design Viability: Based upon the design requirements laid out by the group throughout the stages of concept generation and research, our group has presented within this report a concept solution and design that addresses the specific requirements of the product. The design solution outlined within this report addresses the issues associated with design in order to ensure quality usability, installation, implementation, and maintenance within the product. Based upon the extensive research conducted within this report, the group believes the solution is viable and effective in reducing bacteria based upon the metrics and specifications outlined within this product requirement even without testing results given unforeseen circumstances with regard to COVID-19.

Recommendations: Areas of improvement within this project would actually be a continuation of the project laid out within this report, in which the solution concept can be built using a physical prototype and manufactured to be able to evaluate the effectiveness of the solution to assess its viability based upon the design requirements specified and the procedures prepared to evaluate these metrics. It would be advantageous in future iterations upon the design to conduct a sensitivity analysis within the manufacturing of the physical prototype in order to test and evaluate variations in design features and how they change the overall effectiveness of the solution concept.

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11 Appendix

Alexander Knoop

Comments about the utility of different steps in the engineering design process:

The engineering design process for this project consisted of several key steps in order to develop a functional product. The initial organization of our group's interests was essential in order to find a topic that needed improvement and was of interest to everyone in the group. This process was exceptionally important as it ensured group cohesiveness and helped define what areas we were willing to research. The next key step was defining our challenge space. I found this process to be immensely helpful in our project as it gave a clearer picture of what issues there were in the field, taught us about existing efforts and dispelled any misconceptions we had about the field of Hospital acquired infections. The Generate and Select portion of the process was useful in creating new ideas, however, I think the requirements for a minimum number of ideas per person was not very helpful due to the fact that we had a pretty good idea of what we were interested in before we met the "official minimum" for number of ideas per person. It also included a rubric and analysis that helped the decision making process, which helped determine what ideas were viable. The explore section of the report was useful in working through different ideas and working through potential problems. The prototyping and the design in detail section was also useful for designing the product and creating a plan that others can follow to conduct the experiments and build the product.

Prioritized Recommendations with Justifications:

Some of the key factors that played an essential role in our decision making process. One of the key factors is the utilization of germacideal concepts that were pioneered in recent hospitals that we believe could be applied into other concepts. The issue of bacterial growth in hospital plumbing was brought to our attention after an interview with professor William Guilford who was looking at methods of sterilizing U-bends to reduce ICU infections. Rather than a more conventional solution, we believe that we could utilize a more novel solution based on a UV purification system. While researching I found that this was already used to sterilize HVAC systems and had recently been incorporated in some hospitals to kill Clostridium bacteria after a room was occupied by infected patients. I also had heard of UV light purification systems as a method of sterilizing drinking water from when I was backpacking. These combined factors led us to believe that this could be a viable solution for the purification of the U-bend. WIth this knowledge in mind I would highly recommend that anyone who seeks to carry this project more closely examines how HVAC systems in order to better visualize a functional system. Though we used a water purification model, it would have been helpful to purchase a functional system to compare to. Second I would highly recommend conducting the tests to measure how well the device functions. Due to the COVID-19 pandemic, we were unable to conduct the tests. The value of conducting multiple tests would be valuable in a more in-depth analysis of our solution concept. Third, I would highly recommend setting definitive dates far in advance to meet with any medical experts as they tend to be difficult to contact and typically have unusual schedules to work around. Finally, I would suggest creating several models using different wattage UV-C light bulbs and materials to potentially increase the power and efficiency of the sterilization process. This method could potentially clear up issues which may be caused by light scattering or absorption by materials.