DEVELOPMENT OF A UV LIGHT SANITATION DEVICE COMPATIBLE WITH CENTRAL LINE TO PREVENT BLOODSTREAM INFECTIONS

(Technical Paper)

HIGHLIGHT THE IMPORTANCE OF STRICT HEALTHCARE PROTOCOLS TO PREVENT INFECTIONS

(STS Paper)

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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 the Thesis-Related Assignments.

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Introduction

Healthcare-associated infections (HAIs), those related to postoperative care and specifically central-line associated bloodstream infections (CLABSIs) can lead to severe complications for patients, and ultimately may result in death, annually approximately 2 million patients are infected, and nearly 90,000 are estimated to die (Stone, P. W., 2009). These infections, often preventable with strict protocol adherence, compromise the commitment of healthcare workers to "do no harm" and create complications. Looking at not only the patient end, but infections take a toll on the hospital as a business, prolonged hospital stays result in increased medical costs. Healthcare-associated infections cost U.S. hospitals between $28.4 billion and $45 billion annually to treat, total cost estimated to be as high as $147 billion when accounting for societal costs of early deaths and loss of productivity (*Centers for Disease Control and Prevention [CDC], 2021*). The average cost per case for central-line associated bloodstream infections is one of the most expensive, $48,108 per case (*Agency for Healthcare Research and Quality [AHRQ], n.d.-b*).

Along with advancements in medical devices and infection control practices, infections acquired are largely preventable through strict adherence to safety protocols by professionals in the healthcare system. But despite advancements to prevent HAIs, infections persist due to several factors, this prospectus introduces a dual approach solution to combat this critical issue: adherence to established protocols and the development of a novel technical solution. The proposed solution is a UV light sanitation device that attaches to the central line, designed to sterilize medication entering the bloodstream, eliminating the chance of bacteria entering the patient.

Along with the solution, the ethical concern that HAIs presents to the healthcare system is investigated, including the responsibilities of healthcare professionals to prioritize infection control, maintain transparency, and allocate resources equitably across all patient populations. By addressing both the technical and ethical aspects of healthcare-associated infections, the need for innovation and taking into account the ethics behind innovation is emphasized.

Technical Topic

To reduce the risk of central line-associated bloodstream infection (CLABSI) and post-operative infections, healthcare professionals have developed firm protocols, such as aseptic techniques and consistent maintenance of central lines. However, even with adherence to these protocols put in place, infections still occur, highlighting the need for innovation in additional protective measures. CLABSI is defined as the recovery of a pathogen from a blood culture in a patient who had a central line at the time of infection or within 48 hours before the development of infection. An estimated 250,000 infections occur per year, carrying a significant financial burden. Infections involving gram-positive microorganisms are most common. CLABSIs are most often associated with non-tunneled catheters, which are temporary central venous catheters inserted percutaneously (Haddadin et. al, 2024). The current protocol for CLABSI prevention emphasizes following proper insertion practices, such as pre-insertion hand hygiene and sterile preparation of the insertion site. Designing a device that provides an active sterilization method at the point of entry, this device addresses the limitations of current manual techniques. These infections can theoretically be eliminated by irradiating all fluids and medications with ultraviolet (UV) light using a device attached to the central line. Research conducted by Dr. Thiele of the UVA Health Department of Anesthesiology, along with Dr. Marie of the UVA Health Department of Infectious Diseases revealed a 4-log reduction of *S. aureus* and *E. coli*

bacteria after 10 seconds of exposure to UV light shown in Figure 1 and no degradation of medications commonly used with central lines. The prototype of the device that currently exists involves a commercial off-the-shelf mini-UV unit from AquaSense couples with a custom 3D printed cartridge. For the device to be implemented in a clinical setting, it requires refinement to ensure ergonomic suitability for ICU nurses and a power supply that does not interfere with intravenous tubing or pose a risk of overheating and harming patients.

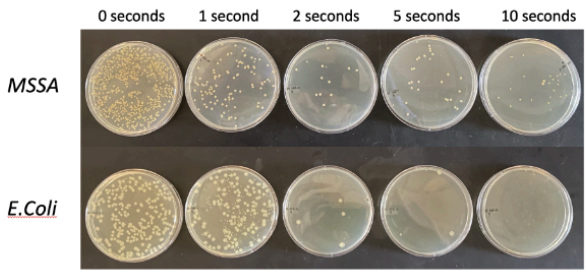

Figure 1. Initial experiments revealed that 285 nm UV light kills MRSA and E. Coli within seconds

The primary aims of this technical project are threefold and will cover two semesters as part of the BME 4063 and BME 4064 Capstone courses. The first aim, focuses on refining the current prototype developed by Dr. Thiele and his team by designing a condensed 3D-printed model that preserves the existing effectiveness in eliminating CLABSI-causing bacteria. This new prototype will incorporate a Luer lock system, along with a two-part disposable insert and reusable housing, to better fit into clinical workflows. Additionally, a power system will be integrated to avoid entangling with IV tubing and central lines, ensuring ease of use and safety in clinical settings. Next aim involves testing and measuring the prototype's effectiveness in reducing bacterial contamination by using common bacterial strains associated with CLABSI, such as *S. aureus* and *E. coli* (Haddadin et. al, 2024). This will be achieved by passing a fluid containing cultured bacteria through the prototype, collecting and re-culturing it, and then quantifying the remaining bacterial load as CFUs. The effect of the prototype on essential

medications like epinephrine and insulin will also be evaluated, ensuring no reduction in drug concentration and achieving a minimum 4-log reduction in bacterial CFUs, in line with previous work by Dr. Thiele's team shown in Figure 2. The final aim addresses the budgetary impact of CLABSI by designing the prototype with manufacturing scalability in mind. Lower manufacturing costs will enhance the device's appeal to hospitals, promoting widespread adoption and ultimately reducing treatment costs for patients.

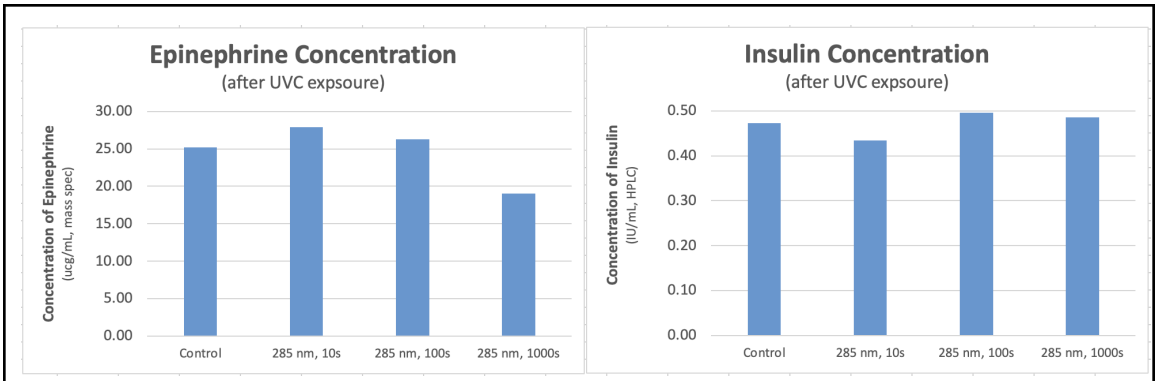

Figure 2: Epinephrine and insulin concentrations did not experience significant degradation after exposure to UV

STS Topic

Infections in healthcare settings increase challenges in the medical/science field and raise ethical concerns. When hospitals fail to implement rigorous infection prevention measures, it reflects a breach of ethical duty and patient trust. Moreover, transparency in reporting infection rates is crucial for accountability. For patients to make informed choices regarding their care, hospitals must be honest about their infection rates. An example of how lack of transparency affected patient outcomes occurred in spring of 2015 in Switzerland. Patients who had undergone open-heart surgery contracted *Mycobacterium chimaera,* due to contaminated heater-cooler devices during extracorporeal circulation (Sax et. al, 2015). In July 2015, a hospital in Pennsylvania also identified patients who had undergone open-heart surgery being infected with

M. chimaera, using the same contaminated device manufactured by LivaNova PLC (*Centers for Disease Control and Prevention [CDC], 2017*). Initial reports about the risk were not widely communicated to all hospitals using the devices, delaying the implementation of stricter infection control measures. Over 250,000 procedures using cardiopulmonary bypass are performed in the United States each year, where the heater-cooler device is implemented in the procedure (*Society of Thoracic Surgeons [STS], n.d.-a*). As a result of that year's incident, many patients remained unaware of their exposure and the associated risks, which delayed diagnosis and treatment for those infected. This incident clearly shows where healthcare professionals' "do no harm" motto was compromised.

Another key ethical issue is resource allocation, as hospitals must invest in staff training, equipment, and infection control practices, which can be particularly challenging in underfunded institutions. Vulnerable populations, including the elderly and those in low-resource settings, are disproportionately affected by healthcare-associated infections. A study examining COVID-19 incidence and vaccination coverage across 81 communities in Los Angeles, California, from July 2020 to September 2021 revealed significant disparities in health outcomes related to socioeconomic status. Lower-income communities experienced higher disease incidence and lower vaccination coverage, emphasizing systemic inequities in healthcare access (*Centers for Disease Control and Prevention [CDC], 2023)*. These findings highlight a broader trend in healthcare where vulnerable populations, including those from lower-income backgrounds, are disproportionately impacted by health-related challenges.

Another study that highlighted infection control being an ethical issue, examined disparities in healthcare access among older adults in low- and middle-income countries, it highlighted that older individuals often face increased vulnerability due to factors that demand

increased care. As people age, problems that are common include “multimorbidity, declines in mobility, and other impairments,” these problems lead to a demand for care that is integrated, local and well-aligned with specific issues (Gao et. al, 2022).

These studies relate to healthcare-associated infections (HAIs), where limited resources in underfunded hospitals and healthcare settings can result in inconsistent infection control measures and increased risk of infection for vulnerable patients. Addressing these disparities is critical in designing effective HAI prevention strategies, as equitable access to infection control resources and preventive technologies, such as the UV light sanitation device proposed in this project, can help mitigate the higher risks faced by these lower income populations and older populations.

Conclusion

To conclude, both technological innovation and ethical responsibility are essential for preventing healthcare-associated infections, especially CLABSIs and post-operative infections. In terms of technology, this study presents a UV light sanitation tool for central lines, providing a novel way to disinfect drugs and lower the risk of infection. This device has the potential to improve HAI prevention outcomes and patient safety when used in conjunction with adherence to evidence-based infection control protocols.

In terms of ethics, this prospectus emphasizes how important it is for healthcare providers to put patient safety, transparency, and equitable access to infection prevention resources first. Technical solutions are important, but for consistent and effective use, they need all healthcare professional’s commitment to ethical principles. When combined, these strategies highlight that preventing healthcare associated infections requires both innovation in technology and people in the field that carry a powerful sense of moral responsibility.

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