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BACKGROUND

Hand hygiene is an integral part of the daily procedure of a health care worker. It is the most essential component in preventing further spread of sickness and disease. One study found that the average hand washing compliance in a teaching hospital was only 48 percent (Bischoff, 2000). Therefore, to increase compliance, a movement to decrease decontamination must be effected, a standard for which has been established by Spaulding (1972). The Spaulding Definition for Decontamination consists of three levels - high, intermediate, and low. The first procedure kills vegetative microorganisms, inactivates viruses, and eliminates some bacterial spores. The intermediate level, which is the one being used for this project, kills vegetative microorganisms, all fungi, and inactivates most viruses. As a basis for comparison, the lowest level kills most, but not all, vegetative bacteria. In the clinical setting, the patient can be exposed to many types of bacteria and microorganisms. The health care worker can also transmit bacteria through his or her own saliva, blood, or just from rubbing his or her eyes. Finally, the patient can become infected with his own flora if proper precautions are not taken. This type of infection is common in urinary catheterizations, for example.

To manage hospital infections, standards have been set to enforce handwashing compliance. According to the Association for Professionals in Infection Control and Epidemiology (APIC) regulations, it is mandatory for health professional's hands to be clean at all times when working with patients (Larson, 1988). If a person's hands are not visibly soiled, an alcohol-based hand rub may be used for decontamination. Alcohol-based gels have become quite common in clinical settings and have become the preferred method of many health care workers due to its efficient and extensive disinfection. Typical alcohol based gels containing 60 to 65 percent alcohol have been proven to kill 99.99% of germs when used correctly (What Everyone Should Know, 2007). When a health care professional transfers from working on a patient to working on a computer, the complying professional, is required to wash his or her hands before and after touching the computer keyboard. This should be routinely done throughout any normal procedure whenever data is entered into a computer; however, this provision significantly slows down a worker's progress in the presence of current technology.

There are many other types of disinfectants used by hospitals and medical staff for various procedures. Hydrogen peroxide is commonly used in clinical settings and is FDA-approved for antimicrobial purposes. It has an unpleasant odor and can cause irritation to the eyes and skin. Triclosan® is a potent antibacterial and antifungal agent that is used in Microban® materials (Schweitzer, 2001). However, some bacteria have developed a resistance to it (Brenwald, 2003), and when combined with chlorine, it can form chloroform (Rule, 2005), which is carcinogenic. Glutaraldehyde is excellent at quickly killing bacteria, fungi, viruses and spores and is commonly used to sterilize medical and dental equipment. It is also colorless and non-corrosive. However, it has a peak exposure limit of 0.05 ppm in most countries, so it has some toxic effects (Takigawa, 2006), and causes severe eye, nose, and respiratory irritation. Ultraviolet lamps are used in laboratories and in medical facilities to sterilize equipment. Its wavelengths, however, are known to cause some kinds of cancers.

With the advancement of technology, these disinfectants have a new niche in the clinical setting. When HIPAA was enacted in 1996, it mandated that, in the near future, all

hospitals will be required to utilize the electronic medical record (EMR) (Connecting For Health, 2004). Hospitals and clinics enter data and patient information on machines called a Computer on Wheels, or more commonly a COW. These come in a variety of different models, but generally all have the same components. There is a monitor, a CPU, and a keyboard that are incorporated into a stand that can be easily moved from one room to another. **FIGURE 1** shows a common COW used in clinical settings. The newer models emphasize its compact shape, easy maneuverability, and safe and ergonomic design for improved workflow and accuracy. These are generally lightweight and can be used by anyone familiar with a common computer. Some models, as the one shown in FIGURE 1, have very little space around the keyboard and monitor and very little can be added before the workspace becomes overcrowded. Other COWs use a laptop computer in place of a desktop computer and have even less space around the keyboard area. Typical COWs run on standard 12V power and are plugged in every time it is wheeled to another room. Many also come equipped with a battery, but it serves as a secondary power source.

Figure 1

Figure 1. This figure shows a COW commonly used in a clinical setting. The design is streamlined for mobility.

These considerations are important in achieving handwashing compliance, but there is a need for tools to be implemented in the clinical setting to better enforce handwashing. Such tools must embrace the advent of EMR while also reducing the amount of time to disinfect, which will ultimately lead to decreased hospital-transmitted infections.

PROBLEM STATEMENT

Hand hygiene is an integral part of a health care professional's job, and the single most important infection control procedure in preventing contamination. This design project is focused on achieving an increase in compliance with hand decontamination when moving from computer keyboard to the patient. The device should expedite the process of hand decontamination while keeping the health care professional and patient safe. It should also be affordable and able to assimilate in to any clinical setting.

DESIGN CONSTRAINTS

The implementation of a device to aid in improving health care hand washing compliance must meet several criteria. Most importantly, it must disinfect the user's hands and maintain the cleanliness of the keyboard and the device itself while keeping the health care professional and the patient safe. The design should not interfere with the health care professional's work and should not allow any discomfort for the user or the patient. It must be safe for prolonged use, meaning that it should also conform to any CDC or APIC regulations, and it should consistently disinfect the user and itself. It should be easily maintained and cleaned while remaining user-friendly. The chemicals incorporated into the device will degrade over time so proper storage devices and shelf life should be considered in the final design. Finally, the product should not impede the user's typing process or ability to easily access the keyboard.

Furthermore, the design must fit seamlessly into the clinical environment, preferably being easily incorporated into the COW and taking up relatively little space. It is expected to be used 20-30 times per clinician, per day, and up to about 10 minute intervals each time. It should be reliable and accurate so it can withstand the mobility requirements. Also, the device should be small because of the COWs' minimalist designs. Any additional bulk will take away from the functionality of the COW design, so the device must optimize the COWs mobility without compromising the device's ability to disinfect the keyboard and user's hands. Finally, the entire device should be cost-effective for it to be accepted by a wide market.

COMPETING PRODUCTS

Currently, there are no products that both disinfect itself and the user's hands while using a COW. However, all disinfecting agents, including hand sanitizers such as Purell®, could be considered competition as well as some types of keyboards. Within the keyboard market, there are some products that prevent bacteria buildup on their surfaces, which makes cleaning

Figure 2

Figure 2: Indukey keyboard with antimicrobial surface.

http://www.indukey.com/content/featured_prod.html

relatively easy. One such product is called InduKey (**FIGURE 2**). It is an ergonomic, cordless keyboard and mouse, which features an antimicrobial surface that is ideal for medical or hygiene-sensitive environments. It also has a special Dura-coating (http://www.indukey.com/content/featured_prod.html) that provides mechanical and chemical resistance. This makes it able to withstand spills in a clinical setting. However, it requires an entirely new keyboard instead of being retrofitted onto an existing one. It only helps prevent bacteria buildup instead of totally disinfecting itself, and it does nothing to disinfect the user's hands.

Another product that is similar is the Unotron® (http://www.unotron.com/) washable keyboard. These are wireless keyboards that are designed to be able to be cleaned under running water or be immersed in an antimicrobial agent to reduce the spread of germs. This neither disinfects itself or the user's hands, but it allows it to be easily cleaned, which can not only save time in a clinical setting but also help reduce bacteria buildup on the keyboard itself.

Microban® keyboards, which use Triclosan® to maintain an antibacterial surface, could also be considered competition. These are common products that can be bought at many different stores that sell generic computer equipment. They only resist bacteria, however, instead of promising a completely disinfected keyboard. These also need to be separately-purchased and do nothing to disinfect the user's hands.

ETHICAL CONSIDERATIONS

The main ethical concern with this design pertains to the patient and user safety. Alcohol is a known irritant to the eyes and can also be toxic if inhaled or ingested in sufficient quantities. If an alcohol spray is incorporated into the design, it must not be easily inhaled or get into the user or patient's eyes. Another concern is that the user's hands wouldn't always be clean. In theory, this device will always provide a clean surface and will effectively disinfect the user's hands, but if not enough alcohol is used or if the device malfunctions, the user will assume his or her hands are clean when there could be lingering bacteria, which could affect the patient. Also, while rare, there could be some people who are allergic to alcohol, which could have adverse effects on the patient or user. Finally, the automatic nature of the device could develop a learned behavior in some users where they become able to avoid the spray when the system is initiated, which would defy the purpose of the device. A heightened awareness of such concerns will be important in the development of a final design.

DESIGN PHASE I

Based on the background research, there exist many ways to disinfect with multiple different levels of disinfection as well. For this project, an intermediate level of disinfection is required. After brainstorming, we came up with many ideas for a design to disinfect the keyboard and the user's hands but due to clinical restraints and client requirements only certain ideas were feasible. We considered the following ideas for our design before finally choosing one design. The product was broken down into two different tasks, one to disinfect

the user's hands and one to disinfect the surface of the keyboard, so three design concepts were eventually developed for each task, based on the initial brainstorm.

UV Light

For this design, we would employ ultraviolet light to disinfect the keyboard. UV energy penetrates the outer cell membrane of the bacteria, passes through the cell body, and disrupts its DNA, preventing reproduction (Lahlou,2000).The device would have a retracting function, much like a retractable cover on a convertible, so that the UV light could disinfect the keyboard while the user was not typing. The device would be wired so that the light turns on when the cover is closed and turns off when the box is opened. Ultraviolet light has been used to disinfect air and surfaces in operating rooms, patient rooms, and laboratories for years (Banrud, 1999). The use of ultraviolet light ensures a continuous reduction in the number of airborne microorganisms (Banrud, 2000). Although ultraviolet light seems to be an effective way to disinfect, there are problems with this design. This concept could not be extended for the disinfection of the user's hands, since prolonged exposure to ultraviolet light has severe health effects, such as melanoma or macular degeneration (Banrud, 2000). Therefore, ultraviolet light could not be used to disinfect the hands, and ideally, we would like our device to disinfect both the hands and the keyboard simultaneously. Furthermore, the COWs have limited space and it would be difficult to incorporate a UV light.

Ionic Silver

Silver has been shown to be an effective antimicrobial agent (Silvestry, 2007). Its ionic form has biocidal effects upon not only bacteria, but fungal and viral agents as well (Guggenbichler, 1999). Silver ions have an affinity to sulfhydryl groups in enzyme systems of the cell wall. In doing this, they interfere with the transmembraneous energy transfer and electron transport of bacterial microorganisms (Guggenbichler, 1999). Furthermore, the ions bind to the DNA of bacteria and fungi, increasing the stability of the bacterial double helix and inhibiting proliferation (citation). For this design, the silver itself would be chemically incorporated into the material of the keyboard. The entirety of the keyboard would have antimicrobial silver incorporated into it so that the keyboard would remain disinfected at all times.

One advantage to this design is that it is a passive system with the forcing function built into the system. The disinfectant is manifested within the keyboard itself; therefore the user does not have to do anything to ensure its cleanliness. Moreover, there is no known cross resistance with antibiotics and no induction of antimicrobial resistance by silver ions (Guggenbichler, 1999). However, some notable disadvantages are inherent within this design. Although the silver will keep the whole keyboard clean, effectiveness in cleaning the hands is not guaranteed because there is no way of knowing if the silver is actually disinfecting or if it is covering the hand in its entirety. A related issue is that it is hard to measure the concentration of ionic silver in the keyboard; therefore it is hard to know how effectively the silver is working. Also, maintaining a constant concentration of silver will be difficult because ionic silver does not exist stably. Additionally, silver is expensive and must be incorporated into the keyboard. Like InduKey, this device could not be retrofitted to an existing keyboard. Instead, a whole new keyboard must be built and, therefore, does not fulfill the design constraints.

Thumbprint Sensor

This design is based on the requirement for users of the EMR to login before accessing a patient's record. Biometric scanners are proving to be increasingly efficient, secure, affordable, and, therefore, prevalent. One type of biometric sensor is the thumbprint sensor . After the thumb is put on the reader, this design would dispense a measured amount of alcohol gel into the palm of the hand, thus allowing the hands to be disinfected. This design provides a forcing function for the user to wash his or her hands. It can be easily retrofitted to the computer and is small enough to fit on a COW. Furthermore, the patient can physically see the disinfectant being dispensed and will be aware that clinician's hands are being cleaned. Although this system seems ideal, no method exists for disinfecting the keyboard. Furthermore, an application for a design with a thumbprint reader to a dispenser has already been filed (Ophardt, H. 2006. U.S. Patent No. 20060213924. Washington, DC. U.S. Patent Application). We seek a more novel application of disinfection technology.

Chamber

This idea consists of having an enclosed system around the keyboard with built-in gloves into which the user inserts his or her hands. Inside this system, an antimicrobial would be contained in order to clean the keyboard, and the gloves would be antimicrobial as well. Technically, this design does fit the goal of the project. It keeps the keyboard and the hands of the user clean. However, this design addresses the problem but does not fit the clinical environment. Clinicians may not want to use this device because it will interfere with typing. Furthermore, although the antimicrobial's efficacy can be assured for a short duration, it could increase the opportunity for infection transmission over time if the components of the device are not meticulously cleaned and replaced. This device reminds us that although a design may address the problem, it may not be the best design for the project goal.

Alcohol-based Spray

Alcohol is currently used in the healthcare industry to disinfect and has been shown to be an effective disinfectant (citation). Furthermore, it has been determined that the overall dermal and pulmonary absorption of ethanol is below toxic levels for humans (Kramer, 2007) at 20 mg/24H. In this design, alcohol will be dispensed via a spray nozzle or several spray nozzles attached to the keyboard, which dispense a fine mist to cover the entirety of the keyboard. An automated command signal will be sent from the keyboard to the computer to dispense alcohol through the nozzles, at an appropriate time that will be determined by a task analysis. This design has several advantages. First, it can complete both the tasks of disinfecting the user's hands and the keyboard in one process, which is our goal for the project. In addition, the viscosity of alcohol allows it to be separated into fine droplets. This property will allow a given volume of the disinfectant to be administered to a larger surface area in less time, and therefore, the mist dispensed will interfere less with the user's task. Moreover, no known resistant strains of bacteria exist. Finally, this design is easily applied to the COWs and can be retrofitted to the keyboard. However, some disadvantages exist with this design. First, creating a mist that will contain fine enough droplets will be a challenge. Furthermore, alcohol is a

drying agent and without emollients will dry out the skin with repeated exposure; however, incorporating emollients into the formulation may leave an undesired residue on the keyboard's surface.

Based on the background information to substantiate these designs and the development of the technology to implement them, they were evaluated for their efficacy in a clinical setting. Criteria were selected from the design constraints to form a design matrix that would aid us in choosing a design to develop further.

DESIGN MATRICES

Design matrices were developed to quantify which design was best suited to increase handwashing compliance most effectively. Rather than constructing one design matrix, we decided to develop two, since there were two distinct tasks that were required to be met in order to achieve optimized compliance. As stated previously, we want to disinfect the keyboard itself, while at the same time disinfecting the user's hands. Therefore, the design matrix for this part of the project was split up into one matrix for disinfecting the keyboard and one for the user's hands. These design matrices rate each design according to multiple categories (FIGURE S 3 AND 4) which were chosen based on the design constraints specified by the client.

Figure 3

Criteria	Weight	UV	Silver	Alcohol Spray
Compliance	20	19	19	20
Interference with task	15	13	15	13
Long term exposure/safety	10	10	10	8
Affordability	10	8	8	9
Length of Service	10	6	6	6
Ease of monitoring	5	5	3	4
Installation	5	4	3	5
Testability	5	4	2	4
Ease of manufacture	5	4	3	4
Patient acceptance	5	4	4	5
Incorporation of both tasks	10	0	0	10
TOTAL	**100**	**77**	**73**	**88**

Figure 3. This figure shows the design matrix used to find the best design for disinfecting the keyboard. The cells highlighted in green indicate categories in which a design scored well, while those in red indicate a weakness of that design.

Figure 4

Criteria	Weight	Sensor	Chamber	Alcohol Spray
Compliance	20	16	19	20
Interference with task	15	10	4	14
Long term exposure/safety	10	7	7	9
Affordability	10	10	8	10
Length of Service	10	8	5	8
Installation	5	4	3	3
Ease of monitoring	5	4	3	5
Testability	5	5	3	5
Ease of manufacture	5	3	4	3
Patient acceptance	5	3	2	4
Incorporation of both tasks	10	0	10	10
TOTAL	**100**	**70**	**68**	**91**

Figure 4. This figure shows the design matrix used to find the best design for disinfecting the user. The cells highlighted in green indicate categories in which a design scored well, while those in red indicate a weakness of that design.

The design matrices for disinfecting the keyboard and the user's hands focus on several important criteria. The most important criteria for these matrices were the compliance and the interference with the task at hand. Compliance is weighted most heavily because it rates the design on how well it forces the user to clean his or her hands or disinfects the keyboard. Furthermore, interference with the task is another important criterion. For example, if the user is typing or entering records, an ineffective design might prohibit them from comfortably entering the information. This could lead to increased length of patient visits, inaccurate data representation, and would be difficult to market. Other categories necessitate further explanation. Installation refers to the ease with which the design could be incorporated into an existing COW. Ease of monitoring refers to the ability of a system to be evaluated for its efficacy over time. The final design we chose was the alcohol spray. This design, as can be seen from the design matrices, showed to be the most compliant, while interfering the least with the task at hand. Furthermore, it is affordable and will not be a long-term threat to the patient or user.

At this point in the design process, our method of disinfection has been chosen. Based on the design matrix, the alcohol spray was determined to be the best choice. It fulfills both tasks of disinfecting the user's hands and disinfecting the keyboard. However, the issue of how to dispense the alcohol still remains. In the next section, we will discuss different designs for applying the alcohol in a safe and reliable manner.

DESIGN PHASE II

Early in the design process we determined that the disinfectant spray mechanism will provide an optimized delivery of the disinfectant to the input device(s) as well as the user's hands. There remain, however, significant considerations as to how we will produce such a spray. In order for this design to be a success, the disinfectant must be administered with as little interference to the typing task as possible; quick evaporation via atomization is an effective way to reach that objective. Atomization of the disinfectant to sizes on the order of microns serves a dual purpose. Primarily, small droplets are less likely to be felt by the user and therefore will not interfere with the typing task. Secondarily, atomization will increase the surface area of the fluid, causing faster evaporation. To achieve this we ordered a ¼" fogging spray nozzle with orifice diameter .015" from McMaster-Carr (P/N 4759T22). This nozzle is designed to deliver 2.22 gallons per hour (GPH) at 40PSIG. It is also designed to produce droplets 9-70µm in diameter. For reference, 2.22GPH equates to 2.33ml/s and the diameter of a human hair is 17-181µm. FIGURE 5 shows a drawing of the fogging nozzle. The primary design constraint rising from the use of an atomizer is the need for a

Figure 5

Figure 5. This figure shows the spray nozzle ordered from McMaster-Carr (P/N 4759T22). It is capable of delivering a cone of spray with a flow rate of 2.33ml/s at 40PSIG

high pressure source.

High pressure is needed to effect atomization of the disinfectant spray. Bernoulli's principle states that an incompressible liquid will travel faster through a small diameter pipe compared to a large one. This is the physical principle which governs the production of atomization. The disinfectant is forced through a small tube, producing a very high velocity stream. This stream then hits the external pin, dispersing the fluid as a cone. The source of this pressure had to be determined, however, which led to the conception of two designs. One design solves this problem using compressed air, while the other utilizes a peristaltic pump. Each of these two designs will be discussed in depth in the following sections

COMPRESSED AIR

Design Summary

The majority of hospital rooms are equipped with access to a high pressure source. The compressed air design provides an effective way to deliver an appropriate dose of disinfectant

Figure 6

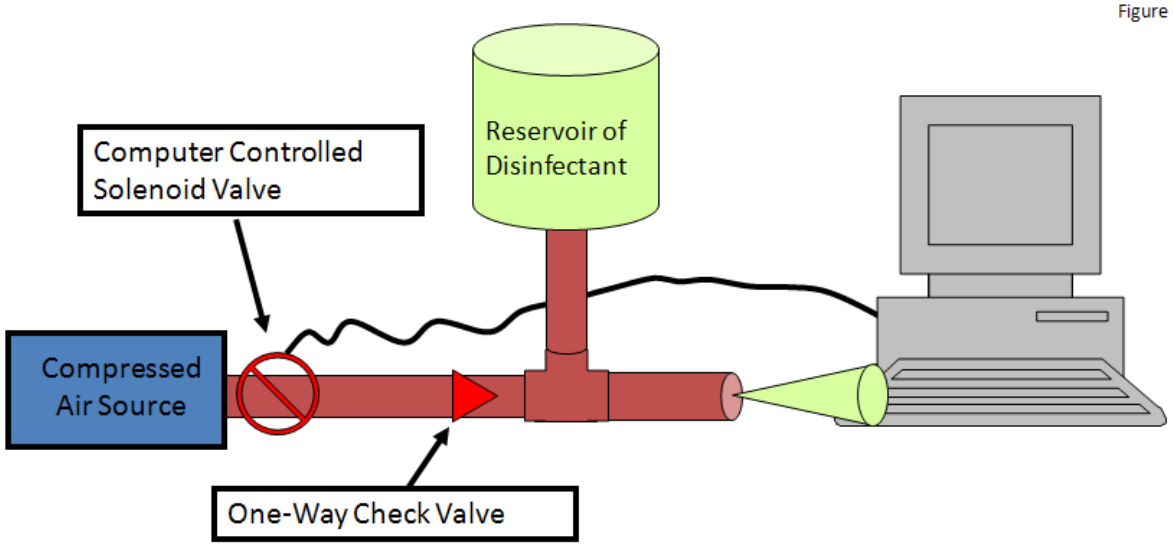

Figure 6. This figure shows a schematic of the compressed air design. A command signal from the computer actuates the opening of a solenoid valve which exposes the system to line pressure. Air takes the path of least resistance to the reservoir tank until the pressure above the disinfectant equals line pressure. From this point the disinfectant is only permitted to flow out through the spray nozzle because of a one-way check valve in place in the line.

to both the keyboard and user's hands using this source. The input of a solenoid valve is connected to a high pressure source while the output end of this solenoid valve is connected to a one-way check valve. A rigid reservoir filled with disinfectant meets with the output of the check valve. This junction is connected to piping, terminating with the fogging nozzle. A schematic of this design is shown in FIGURE 6. At the time of use, a customized circuit (FIGURE 7) delivers an impulse from the computer to the solenoid valve to open for a predetermined amount of time. The volume delivered (a function of how long the valve is open) will be

determined from the final composition and the concentration of disinfectant required. This design requires a significant amount of equipment but yields reliable results. Upon opening the solenoid valve, the released air will take the path of least resistance to reach a lower pressure. Initially, this path will be in the air pocket of the reservoir, so air will continue to flow into the reservoir until the pressure above the water equals the line pressure. This container must be rigid because of the pressure to which it is exposed. After this point, the most energetically favorable action for the air is to force the liquid out of the pipe through the nozzle. As a safety measure, however, a check-valve after the solenoid valve will prevent any backflow of liquid into the compressed air source.

Figure 7

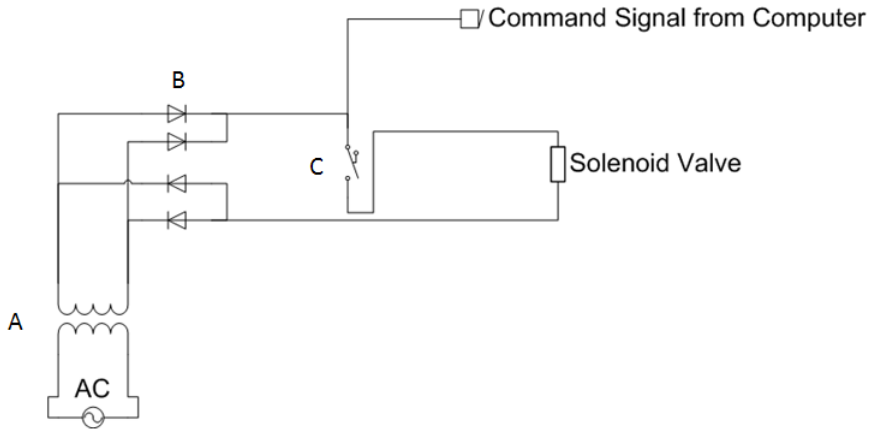

Figure 7. This figure shows the customized circuit to actuate the solenoid valve. The transformer labeled A will convert line-AC voltage to 10VAC. Part B is the array of diodes to transform 10VAC to 10VDC. Part C is the relay which closes the switch to permit current flow to the solenoid valve.

Advantages

This system is an effective design for several reasons. It is cost-effective and has few moving parts. The most expensive component to this design will be the solenoid valve. These valves range from $70.00 to $400.00 (McMaster-Carr), but the solenoid required for this application can be on the low-end of this price spectrum since only one simple function is required. The costs associated with the other components of this design are practically trivial. The check valve and disinfectant reservoir are generic and can be produced very inexpensively. The other principal advantage of this design is the ease of maintenance. Since this design is based off of several invariable physical properties, there are very few ways in which the system could malfunction. The only active piece of this design is the solenoid valve. Solenoids can be ordered to be “normally closed.” This means that even if the valve malfunctions, it will be locked in the off position, preventing free-flow of disinfectant.

Disadvantages

Although the compressed air design works well on paper, it is not easily translated into a marketable product. The most inhibitory factor of this design is the source of compressed air itself. COWs are designed to fit seamlessly into the clinical environment. This requires mobility,

maneuverability, reliability, and aesthetics. Although the compressed air design may be reliable, it falls short on the other three criteria. Since the device is dependent on compressed air, either a tap into the hospital's line or a tank of compressed air will be required. Both routes significantly reduce the mobility of the COW. Tapping into the hospital's line will require the device to be plugged in and removed each time it is taken from one patient's room to the next. It also requires the COW to be physically close to the source of compressed air. The cords required to make this device operable will only contribute to "Spaghetti syndrome," simply put, the mess of cords wires and tubes required to monitor a patient. "Spaghetti syndrome" has been a problem for hospitals for decades. It has been reported on by Cesarano in 1979, and purported solutions to its problems are evident in the literature. Therefore, a design with fewer connections between the COW and the room in which it is being used is preferred. However, using an air tank to supply the COW with compressed air will need to be securely attached. The extra space taken up by the tank will also significantly reduce the maneuverability of the COW. Finally, the compressed air design will require a large rigid container to house the compressed air. This will reduce the aesthetic appearance of the COW and also contribute to bulk.

PERISTALTIC PUMP DESIGN

Design Summary

Peristaltic pumps are already used for an array of hospital applications, including drug delivery, kidney dialysis, blood transfusions, and suction of bodily secretions, so achieving heightened hand washing compliance using such a mechanism would be readily accepted in a clinical environment. Peristaltic pumps use positive displacement to regulate the flow of liquids, whether by rotary, reciprocating or a diaphragm-type design (Serven and Rhodes, 1960), as shown in FIGURE 8.

Figure 8

Figure 8. This figure shows the three types of pumps. From left to right they are rotary, reciprocating, and diaphragm. © Process Pumps Corp.

Positive displacement traps a certain volume of fluid and then forces it to a new location. Positive displacement is actuated by a motor that provides some form of mechanical stimulation to push a liquid forward at a given speed. This ability to provide a constant flow

characterizes peristaltic pumps, and different pump designs enable this trait by regulating the pump's displacement of fluid, the rpm of the motor, and the pressure of the system. The flow capacity of a pump is proportional to the speed of the motor if slip is neglected. However, the high pressure demands of this design require durable parts to maintain this proportionality. These pumps are usually manufactured with special tubing, which is the true mechanism by which the pumps function. Depending on the specifications of the tubing, the pump is able to adapt to a variety of medical, industrial, and agricultural applications, which allows for the transport of a range of fluid compositions and hazard levels (Ebelhack 2001). This special or active tubing is housed within the peristaltic pump. Simple input and output connections can join the active tubing with generic tubing externally.

The pump functions by mechanically occluding a length of tubing, either by rotation of a footed rotor or by linear compression of a portion of the tube, which forces the fluid to displace by the amount it was occluded. Once the rotor passes, this portion of the tubing is opened, allowing more fluid to enter the tube by a slight suction gradient. Simultaneously the adjacent section of tubing is occluded by the rotor. With each subsequent occlusion, the fluid progressively moves through the tube at a specified rate.

In this design (FIGURE 9), a rotary peristaltic pump with active tubing that can withstand higher pressures would be used to displace the disinfectant from a reservoir and through a fogging nozzle via flexible tubing. The active tubing will need to comply with the chemical compatibility and pressure requirements of the system, so it will most likely be a firmer

Figure 9

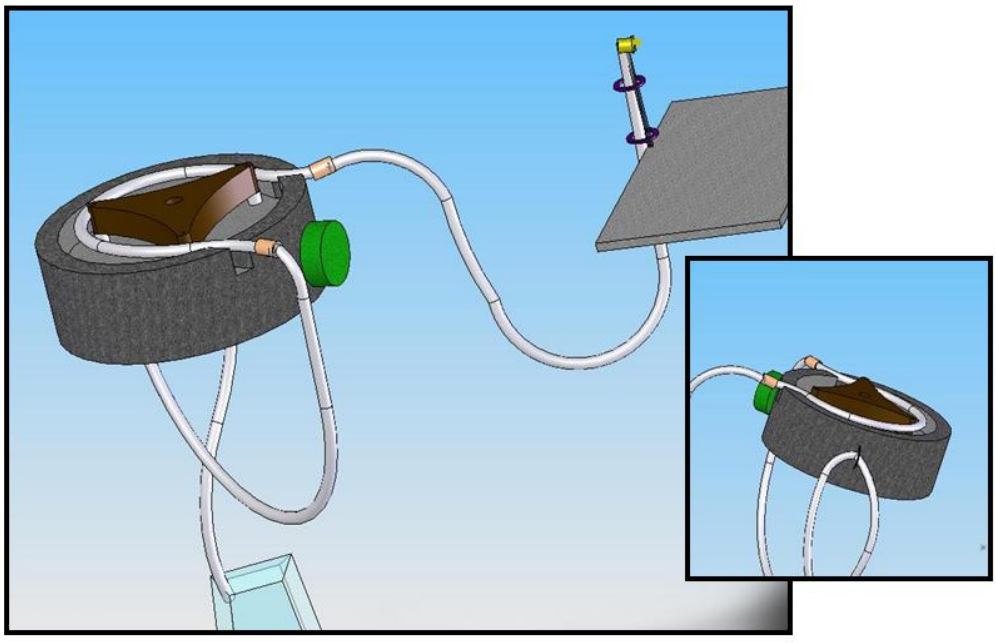

Figure 9. This figure shows how the peristaltic pump design could be assembled. A key feature is the tubing, whose length could be varied according to the design of the COW. On the left is a front view, showing how the tubing connects the reservoir to the pump and to the spray nozzle, which is mounted on a stand. On the right is a rear view, which shows how the input tubing can be fixed to the pump itself.

material like Norprene® or PharMed®, which can function under pressures up to 125 psi (Ebelhack 2001), however a trade-off with firmer tubing is greater torque from the rotary motor in order to compress it. Other considerations for the active tubing will include the optimal inner and outer diameters for the desired flow rate, the material's life expectancy, the porosity of the tubing material, and its cost per unit length. Depending on the rate of rotation and the orientation of the feet in the rotor, the pulsatile flow can approach constant flow. The tubing in the pump for this design will be occluded using a rotary mechanism, since this approach allows for the most constant flow. If the rotor contains feet that are separated by 120 degrees, they will model three phase power. This creates constant power output from the pump. The motor can easily be powered by an electrical outlet, and the entire pump would be automated to initiate the fogging when the user logs into the computer system. One final feature of the design is that the disinfectant would be supplied to the pump tubing from a flexible reservoir. Since peristaltic pumps operate under positive displacement to generate flow, the reservoir could even be contained in a plastic bag. This would allow for easy replacement of the disinfectant once its supply is exhausted, and it would also allow for easy storage on the COW.

Advantages:

There are several advantages to the peristaltic pump design, principally its capacity for efficient delivery of the disinfectant. The pump is stationary and can be small in size, which would allow it to be mounted on the COW and maintain the mobility of the COW. Peristaltic pumps are also straightforward to troubleshoot, since each of the components of the pump can be easily removed and replaced, if necessary. Furthermore, the fact that the pump uses positive displacement would give much more flexibility to the rest of the device, especially in the way that the disinfectant is stored. Finally, the peristaltic pump design requires few parts, all of which can be purchased on the market, so the overall cost of the device would be reduced by this design feature.

Disadvantages:

Although the design offers promise in several areas, there are also a few obstacles to its implementation. This design would be somewhat difficult to repair, since the tubing required to operate the pump will be manufactured to precise specifications in order to ensure accuracy of the product's performance. Furthermore, the high pressure needs of the device will limit the options for finding a low-cost, high pressure, small size pump. Although appropriate sizes and flow rates will not be difficult to find commercially, the cost of a high pressure pump may be significantly increased. Finally, the prototype phase of the device is likely to be fairly costly, since purchasing pumps on the market are typically more expensive due to variable flow rate options, which a final product will not require. However, custom fabrication of the pump at this stage to meet its design needs would be unrealistic. In terms of the final product, custom

fabrication will become an advantage, since the device will have predetermined torque, flow, and tubing specifications, thereby reducing the cost.

DESIGN MATRIX II

Since both the compressed air design and the peristaltic pump design provide solutions to the disinfectant delivery problem, another decision matrix was formed to determine which design will best address the problem statement. The decision matrix is shown in FIGURE 10. The design which fulfilled the criteria the best was awarded full points, with the second design receiving points based on its merit. The most important factor in this decision was the

Figure 10

Criteria	Weight	Compressed air	Peristaltic
Mechanical Complexity	25	10	25
Cost	20	20	10
Size/mobility	15	5	15
Disinfectant Storage	15	5	15
Life in Service	10	5	10
Installation	10	5	10
Power Source	5	2.5	5
TOTAL	100	52.5	90

Figure 10. This figure shows the decision matrix for the compressed air design as well as the peristaltic pump design. The better suited design was awarded full points for each category, with the second design receiving points based on its merit.

mechanical complexity. The peristaltic pump received full points for this category since it involves fewer parts than the compressed air design. The next most important consideration for these designs was the cost to develop the prototype. In this category the compressed air was awarded full points since the materials to develop the prototype will be the least expensive. Peristaltic pumps currently available on the market are designed for precise flow control. Increased precision causes these pumps to be more expensive. Once the correct flow and torque required by the pump are known, it will be easy to build a cost-effective, non-adjustable pump for the market. Tied for the next most important criteria are the disinfectant container and the size/mobility of the final product. In both cases the peristaltic pump was awarded full points. The disinfectant reservoir for the peristaltic pump does not need to be rigid, as the pump only creates high pressure on the output side of the device. Also, the peristaltic pump is more minimalist in its required materials; therefore it will be more easily implemented onto the COW. The next criteria, also tied, are the life-in-service and the installation. Again, full points were awarded to the peristaltic pump. The peristaltic pump will have fewer moving parts;

therefore, it is less likely to fail than the compressed air. In conjunction with the longer life, installation will also be easier with the peristaltic pump because it has fewer parts. Finally, the power source required to drive the pump was considered. The compressed received full points for this category, since the circuit required to interface this device with the computer will be easier to design than for a commercially available peristaltic pump. Once all the weights were summed, the peristaltic pump was decidedly the better design option to pursue.

FUTURE WORK

Although the concept of the design is strong, there are several remaining benchmarks that our team hopes to attain by the end of the semester. The focus of our research is three-fold: we aim to determine and test the most effective disinfectant for use as a surface and hand decontaminant, we will develop and test a working pump design that can efficiently and adequately deliver the disinfectant to the keyboard, and we will optimize the atomization capacity of the disinfectant fluid by testing the nozzle and perfecting the formulation of the disinfectant. Additionally, we will develop a mechanism to automate the device by the end of the semester. These objectives will be accomplished by creating a first-generation prototype of the entire device and then carrying out several tests to determine its efficacy, both biologically and mechanically. First, we will observe a clinical setting where COWs are used to confirm the design requirement. Once the fogging mechanism is prototyped, the first test will be to establish the optimal nozzle placement so the entirety of the keyboard and hands are covered. We will also test the necessary pressure and flow requirements to produce an optimal spray, and we will test the rate of evaporation of a 65% alcohol solution, which will further address the mechanical constraints of spraying the disinfectant. Then, we will assess how effectively the alcohol spray decontaminates the surface by obtaining cultures of keyboards and hands as well as a glove juice test and performing a preliminary assessment of the biological response to the device. Finally, we will perform a task analysis in assessment of how well our device improves hand washing compliance. This will serve as a preliminary evaluation of the product's overall efficacy. Ultimately, our aim for the semester is to develop our product to the point where it can be accepted by a manufacturer for further device development and production.

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