NURSING (RNSG) 2535: INTEGRATED CLIENT CARE MANAGEMENT: NURSING IV. Adam has used the standard format of a scientific paper to describe his work and to place it in context with other work in the field. His Introduction describes the results of previous work on the methods that have historically been employed in the hospital setting to reduce or prevent acquired infections and he discusses the published studies that have been conducted with the use of copper. His Methods section includes the methods he used to calculate the cost-benefit analysis and the methods he used in his laboratory experiments. The large amount of data he produced with his experiments is presented in tables and summarized in the text of his Results section. The implications of his work is discussed in the Conclusion section of his paper. Adam uses the conventions of scientific writing to present his work clearly and to support his conclusions. This is an outstanding example of critical thinking and collaboration.

--Carol Girocco

Antimicrobial Copper in Healthcare – a Cost Benefit Analysis with a Primary Study on Oxidation's Effect on Copper's Antimicrobial Properties

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Abstract

For several years copper has been known to have antimicrobial effects. Last year the Environmental Protection Agency approved its use for infection control purposes. Hospital-acquired infections continue to be a public health concerns despite innovations in curbing them. They increase the time patients stay in a hospital, cost to care for patients and, of most importance, can lead to further morbidity for patients and even mortality. However, many of the interventions attempted require education of visitors, staff training and commitment, and have had only moderate success. Copper surfaces in hospital rooms could avoid these concerns while constantly decreasing the bacterial load left by patients, family members, visitors, as well as the healthcare team. This could prove invaluable in a hospital setting, but copper's cost can be limiting. Despite a recent report that over fifty percent of hospital-acquired infections can be avoided with copper surfaces, no hospitals have adopted widespread copper surfaces. A large part of this delay in advancement most likely is in regards to cost and upkeep. To overcome this hurdle the benefit of copper must outweigh the cost. The cost/benefit must be in regard to: cost to upgrade to copper versus money saved by preventing infection. To truly understand the long-term cost, oxidation's effect must be understood in regards to copper's antimicrobial activity. To understand this, copper plates were artificially oxidized with heat, and then tested in regards to their antimicrobial effects. The oxidized copper plates proved to have a more antimicrobial effect (i.e. they killed more bacteria, faster) than new copper plate, showing that over time, copper surfaces become slightly more antimicrobial. This makes copper surfaces a long term asset in decreasing hospital acquired infections. Given copper's long term, constant effect, in preventing infections, the cost of upgrading to copper surfaces can be justified.

Introduction

As modern medicine ascends to new heights some old problems remained to be solved. Hospital acquired infections (HAIs) have been prevalent for a very long time and despite recent campaigns to reduce their incidence the problem remains. HAIs have actually become worse over the last decade with the emergence of more antibiotic resistant strains of bacteria. In 2013 totally drug resistant strains of Tuberculosis are being found across the world (National Post, 2013). Recently the first completely drug resistant *Staphylococcus aureus* strains were discovered (Nikaido, 2009). Collectively *Pseudomonas aeruginosa* has also become resistant to all antibiotics (Nikaido, 2009). We must begin to prevent these infections in the face of bacteria that are resistant to all known treatments.

Many methods are now, or have, been explored to decrease the rate of HAIs. These methods range in price and complexity. The most simple and proven way to decrease HAIs is proper hand hygiene (DePaolo et al., 2007). Hand hygiene can be effective at reducing HAIs, and seems exceedingly simple. Hand hygiene should be drastically decreasing HAIs but it hasn't. The two main factors in this reality are poor skill and poor compliance (Szilágyi et al., 2013, Pittet, 2001). A large scale study in Singapore found that only 72% of staff in a 1000-bed hospital effectively washed their hands (Szilágyi et al., 2013). It is unknown how well the general public washes their hands but it is doubtfully any better than trained professionals. Compliance issues are the real downfall of hand washing despite many campaigns (Pittet, 2001). The Centers for Disease Control and Prevention and the World Health Organization both have hand hygiene campaigns to increase compliance but the results are varied. Some reports cite compliance at less than 50% (Pittet, 2001). Hand hygiene is effective and must remain a forefront method of decreasing HAIs, but it needs part of a larger system to reducing infections.

Background

Instead of solely relying on healthcare staff to reduce HAIs, the healthcare facility itself should also participate. This is possible with the introduction copper surfaces. Copper has a well-documented antimicrobial effect (Michel et al., 2012, Varghese et al., 2013, and others). This effect is related to copper ion reactivity and its interaction with bacterial membranes (Santo et al., 2012). Cells make and store energy through the use of ion transport chains (Bauman, 2011). Membrane proteins pump hydrogen ions across the membrane creating a proton gradient (Bauman, 2011). The cell can then use this gradient to fuel the process of oxidative phosphorylation to create adenosine triphosphate (ATP) (Ibid). ATP is a molecule that can store readily available energy (Ibid). Eukaryotes have mitochondria perform this process across the mitochondrial membrane within the cell. Bacterial cells do this across their only membrane, meaning their ion transport chains pump hydrogen ions into the environment (Ibid). The electrochemical properties of copper ions can disrupt the flow of hydrogen across the membrane essentially stopping cellular respiration (Varghese et al., 2013). In some species, specialized ATP synthase membrane protein are meant to allow a moderate amount of copper ions through – too many however, could decrease or completely disrupt hydrogen ion influx needed to phosphorylate ATP normally (Grass et al., 2011). Where it is true that scant amount of copper ions are needed from many intracellular processes, mass copper ions from bacterial contact with copper plates can damage the membrane itself (Grass et al., 2011). It is not entirely clear what the mechanism is behind copper's ability to punch holes in cellular membranes, but Santo et al proved that after a bacterium has been killed by copper, copper ions can be found within the cell. Scant amounts of copper ions are needed by bacterial cells for some cellular processes, however, when put directly onto copper the intended influx is overwhelmed (Varghese et al., 2013). Many bacteria have enzymes that help buffer the reactivity of copper ions, but these enzymatic buffers were meant for scant amounts of environmental copper, not for direct contact with copper plates/surfaces (Varghese et al., 2013). Another possible answer for the membrane damage from mass copper ions is a single copper ion's affinity for oxygen. This affinity could pull oxygen ions through the cell damaging the membrane. The holes in the membrane act as a conduit to allow more copper ions into the cell wreaking havoc on all cellular processes including damage to DNA (Grass et al., 2011). Many bacteria die within minutes of exposure (Santo et al., 2011).

The current standard metal surface in any hospital is stainless steel. Stainless steel surfaces resist rust and tarnishing over long periods of time. One benefit of stainless steel is that it can be cleaned many times without obvious damage. However, even when cleaned with strong antimicrobial chemicals some bacteria may remain (Michaels et al., 2013). Surface scratches, too small to be seen, may harbor infectious bacteria while giving refuge from cleaning products (Michaels et al., 2013). Wiping a door handle with a bleach wipe would likely kill most bacteria but a small number (dependent on species) is all that's needed to establish a colony. If that small number of microbes is moved from the door handle to a patient there is a potential for an HAI. Even though stainless steel is easy to clean, and weathers well, it acts as a reservoir for bacteria, where copper acts as an antimicrobial.

Copper is just starting as a viable antimicrobial surface but its potential is proven. Copper was put to the test in several intensive care units (ICUs). This study by Salgado et al showed the potential copper has against HAIs. Three hospital ICUs had copper surfaces added to the rooms (Salgado 2013). In total, 16 rooms were studied – 8 test rooms with copper surfaces and 8 control rooms. All test rooms were adjacent to control rooms (Ibid). Bed-control personnel were unaware as to the changes in the test rooms but treatment teams were. Up to six copper surfaces were used in each room. Bedside tables, IV poles, visitor chair arms and bed rails were introduced to all rooms. Several other items were dispersed amongst some of the rooms to equal six surfaces in each room; these included the nurse's call button, laptop hand rests, computer mouse, and the bezel of touchscreen monitors. The study was conducted over a year with patients being assigned at random. In the test rooms with copper 294 patients were assigned over one year. Of that 137 patients received care with all six copper surfaces. The other patients received care in the rooms but one or more of the copper surfaces were removed at some point, generally related to staff not knowing the surfaces were needed for a study. The control rooms were assigned 320 patients, of which 277 received care. The copper rooms decreased HAIs by more than half when compared to the control rooms. The study also tracked bacterial colonization of the rooms. This is also referred to as bacterial load relating to how many bacteria are present on surfaces in the room at any given time – a decrease in bacterial load generally decreases risk for HAI. A *sterile* surgical suite would have a bacterial load of zero. The rooms with six copper surfaces had a decrease in bacterial load of over 83% compared to the control rooms.

The results of the Salgado study were impressive and attest to the possibilities copper can offer in decreasing the incidence of HAIs. This study had six copper surfaces in the test rooms, but this number could be increased. Also, the surfaces that generally have a high bacterial load, namely door handles, were not copper. With these results, and substantial room for adding more copper surfaces to further decrease bacterial load, why are copper surfaces not ubiquitous in hospitals? The most significant answer is cost. There is a factor of unawareness of copper's antimicrobial effects but it is not as difficult a burden when compared to cost. The surfaces in the Salgado study were custom made. Since that study, and the EPA's certification of copper as an antimicrobial surface, medical copper manufacturers have increased in numbers lowering the cost of copper surfaces. However, cost benefit studies are not readily available. For copper to find a place in hospitals the benefit must clearly outweigh the cost. The cost of copper can be obtained from various manufacturers. The benefit can best be measured by the cost of HAIs.

Cost/Benefit

Obtaining the cost of copper products from the companies that offer them must be done through individual correspondence with those companies. The current industry standard is for customers to contact sales representatives for quotes on product needs (i.e. companies do not regularly post their prices). No one company offers all of the copper surfaces needed to update a single room, much less an entire hospital. Several companies are willing to make anything custom and contracting with one of them to outfit an entire hospital may be cost effective but would take considerable commitment and deposits. To begin updating a hospital, it would be more practical to renovate sections of the hospital at a time (e.g. floor by floor). For this study, to obtain a base cost per room and per floor, contact was made with several manufacturers to obtain prices on their individual products. The products were chosen based partly on what was used in the Salgado study, availability, and the needs of a standard medical/surgical room in a hospital.

To average what is needed for a hospital room Memorial Hermann The Woodlands was used as a model. This is a large, 258-bed tertiary care center in Texas with their basic medical/surgical floor as the model (About Our Hospital [Memorial Hermann The Woodlands], 2013). Using Memorial Hermann's standard medical/surgical room as a base design several surfaces were identified to upgrade – bedside table, bed rails (2), cabinet hardware (6), door handle, push door handle (made to be opened by pushing a bed into it), sink, sink faucet, IV pole, visitor armrests (2), and wall outlets (6). The bedside table, visitor chairs and bed rails are highly touched surfaces and were included in the Salgado study; upgrading them would be prudent. However, from the manufacturers that responded by email, none made them. New bedside tables without copper tops and stretchers without copper rails can be purchased for hundreds to thousands each, they would likely be much more with copper surfaces. To avoid the costs of completely new furniture, the company Frigo Design makes copper surface upgrades at a base price of sixty dollars per square foot with an average countertop upgrade of 160 dollars (J. Bernet, personal communication March 25, 2014). Using these estimates Frigo Designs could make custom bed rails, armrests, and bedside table tops for fractions of replace the entire piece of furniture. Using Frigo Design's estimates a single bedrail could be made for approximately ninety dollars, an armrest for the visitor chairs for sixty dollars, and a bedside table top for 160 dollars. These items could be manufactured to fit existing furniture and then installed by existing hospital staff.

Many items are made as standard production items. The list of these items grows regularly. Midbrook Medical was one of the first companies to begin making antimicrobial production items. They specialize in medical/surgical trays and cabinets, but also make IV poles completely covered in antimicrobial copper for just over seven hundred dollars (T. Vannest, personal communication, March 25, 2014). Elkay Manufacturing makes a wide variety of copper sinks. For this analysis one of their base models was used that closely matched the model hospital's patient sinks that costs $864 (D. Palenik, personal communication, March 26, 2014). Trimco Manufacturing is one of the few antimicrobial copper distributors that post their prices. From their price list they have standard door handles for $110, hands free sink faucets for $417.90 (motion activated), a variety of cabinet hardware averaging about fifty dollars a handle, and hospital push door handles for $462. Copper light switch covers and wall outlet covers can be found at many websites for an average of twenty dollars per piece (Antimicrobial Copper n.d.). The sum of these products is found below in Table 1. When totaled following the medical/surgical room model, one room can be upgraded for $3439.95. Each medical/surgical floor has 36 beds.

In addition to the patient rooms, the floor itself has many stainless steel surfaces to be upgraded – the summary with totals is below in Table 2. Of most importance were the many computer keyboards and mouses – 24 of each per floor. Of these 24 computers at least six are mobile (meant to go with nurses into patient rooms). Operator Interface Technologies offers copper plated keyboards and mouses for three hundred dollars and seventy-five dollars respectively (B. Nolan, personal communication, March 24, 2014). Also found on the floor were sixty more cabinet door handles, forty-two door handles, four automatic door switches, and twelve additional IV poles to be used as needed. The automatic door switches can be purchased for $120 from ATEK Access Technologies (J. Kritta, personal communication, March 31, 2014). To upgrade an entire medical/surgical floor would cost $149,410.44. This seems to be substantial but it must be held only in regards to monies saved by its initial costs.

To calculate the benefit of copper its cost must be weighed against the possible revenue saved by preventing HAIs. The most practical way to achieve this is by estimating the average cost per HAI any given facility might pay out. This could be as simple as dividing the national amount spent on HAIs by the incidence of HAIs. However, these two figures are not readily accessible. The greatest barrier to knowing these data is reporting. Hospitals are not required to report incidence of infection. The hospitals who do report generally do so to an accrediting agency that does not release actual numbers, only benchmarks and comparisons to other hospitals.

Item	Cost	Quantity	Total
Bed Rails	90.00	2	180.00
Bedside Table	160.00	1	160.00
Cabinet Hardware	50.00	6	300.00
Door Handle	110.00	1	110.00
Push Door Handle	462.00	1	462.00
Faucet	417.90	1	417.90
IV Pole	706.05	1	706.05
Sink	864.00	1	864.00
Chair Armrest	60.00	2	120.00
Wall Outlet	20.00	6	120.00
Grand Total Per Room		3,439.95	
Grand Total Patient Rooms on Floor		123,838.20	

Table 1 – summary of surfaces to upgrade in each patient room with totals in dollars

Item	Cost	Quantity	Total
Cabinet Hardware	50.00	60	3000.00
Door Handles	110.00	42	4620.00
Computer Keyboard	300.00	24	7200.00
Computer Mouse	75.00	24	1800.00
IV Poles (extra)	706.05	12	8472.24
Wall Switch	120.00	4	480.00
Total Per Floor		25,572.24	
Grand Total Upgrade Per Floor		149,410.44	

Table 2 – summary of additional surfaces found throughout floor (hallway, nurses' station, etc.)

The amount spent per year on HAIs is often estimated at 45 billion dollars; however, there seems to be no direct source for this number. The estimate of forty-five billion is taken from a 2009 CDC report which used information over a several year span, with the figure being on the high end (Douglas, 2009). The low end of that report was 28.4 billion – a large difference. In that report the annual cost was adjusted by consumer price index from previous reports. The range yields understanding to the concept that this is not a simple figure to come up with. In that CDC publication by Douglas it listed 1,737,125 HAIs per year with catheter associated infections averaging around one thousand dollars per infection, to surgical infections averaging around thirty-five thousand dollars per infection in 2007 dollars. Already one can see a benefit when compared to only 3,500 dollars to upgrade a room.

A true side by side comparison would be helpful but requires a more precise figure. A comprehensive study of the CDC numbers was done by Hassan et al in 2010. In this study they solidified an average cost per infection using many data points and several statistical equations. Hassan et al put a solid estimate of $10,375 per hospital acquired infection with an increase of hospital stay of 3.30 days. This study, to date, is the only peer reviewed calculation for estimating HAIs. The American Hospital Directory reports that there are 4,013 hospitals in America. With the number of HAIs per year from the CDC report by Douglas, each of the 4,013 hospitals would have a projected 432 HAIs per year. With Hassan's average of $10,375 per infection any of these hospitals could expect to pay $4,491,071.98 every year on HAIs. However, by that math we only spend 18 billion a year on HAIs. Given the mass discrepancy, the average cost per infection serves as a better benchmark.

At an average cost of $10,375 per infection, the cost to upgrade a single room with antimicrobial copper surfaces would be justified by preventing just one infection. The cost of upgrading one medical/surgical floor, in the hospital model, at just under 150 thousand dollars would be justified by preventing only fifteen infections. In the Salgado study, each room prevented at average two infections per year. If a medical/surgical room performed similarly then an entire floor of thirty-six rooms could save $747,000 in one year. One room would save over twenty thousand in one year. In the hospital the model is based off of, there are 254 beds, but only three medical/surgical floors. The difference lies in the many specialty beds – emergency room, surgical suites, intensive care rooms, etc. Each of these specialty rooms has its own needs, but the benefit of using a med/surg room as the base model is it can readily accept most patients from any of these specialty rooms. Some specialty rooms would cost more to upgrade (e.g. an operating room) and some would cost less (e.g. a pre-op holding room), the common denominator is the med/surg room that can accept a patient from both. Going by the med/surg room the cost to upgrade all hospital rooms would be $2,635,250 – only three and a half times what could be saved in one year from one med/surg floor upgrade. This mean one could outfit all the rooms in the model hospital from the money saved from updating one med/surg floor after only three and a half years. Updating the three med/surg floors could justify the entire hospital's expense in just one year.

These figures come with a certain amount of assumption. The standard cost for a hospital acquired infection is around ten thousand dollars; however, a catheter associated infection may cost seven hundred dollars (Douglas 2009). In that case each room would have to prevent five infections to pay for the upgrade. In that same regard one ventilator associated infection could cost almost fifty thousand dollars, where preventing one could pay for fourteen copper room upgrades (Douglas 2009). Copper, however, could be a constant between these two scenarios. Copper can reduce the bacterial load in a room by 83% (Salgado et al., 2013). The reduction in bacterial load decreases the risk of both a catheter associated infection and a ventilator associated infection similarly, as the overall bacteria in the room has been drastically reduced, thereby reducing the chance of any infection. Because copper acts constantly and consistently, its use can ascend these levels of assumption. Copper will work to prevent a catheter associated infection in the same way it may prevent any other infection, making the overall cost saved per infection realistic. The only barrier that may stand in the way of copper's continual effect on bacterial load is what happens to copper over time – copper is prone to oxidation which could alter its antimicrobial properties.

Resistance to oxidation is one of the aspects that make a stainless steel surface more desirable than other standard surfaces. Copper stands above other surfaces as it has an antimicrobial effect. However, if this effect is only temporary, instillation of copper may not yield the time it needs to prevent enough infections to justify its costs. To justify copper's expense it would have to be effective over several years. Copper's actions against microbes are contingent upon its ability to interact with the microbes. Oxidation could prevent copper ions from reaching microbes; hence, this possibility must be tested. To test this, copper plates were artificially oxidized, then analyzed to see if they retained their antimicrobial properties.

Methods and Design

Oxidation

There are several means to oxidize copper to simulate aging. The surface of a copper plate goes through many changes before it stabilizes around the twenty year mark (Copper Weathering and Patina Chart for Weathervanes 2007). To speed up this change there are two main methods – chemical and heat. Artificial patina, an acid preparation, can give copper its well-known green state of oxidation very quickly. The Copper Development Association used this process in its study of oxidation for the EPA registration of copper as an antimicrobial surface. The project manager for this research group stated that the results were too varied (A. Estelle, personal communication, February 10, 2014). Their conclusion was that the chemicals used in the process were too influential to the test. Using this information, the copper in this project was oxidized with heat.

Heat speeds any chemical process including the oxidation copper undergoes with its surrounding atmosphere. A propane torch was used to speed the oxidation process; once turned on the flame was not adjusted. The torch was held with the tip of the inner flame touching the plate. The flame was slowly moved in a small oval about an inch wide. When the flame was removed, the plates changed color quickly, and uniformly, up to within 2 centimeters of the corners. Several plates were made at different time intervals – 15, 30, 45, 60 seconds and one plate for five minute. The final test used the 30 second, the 5 minutes plate, one untouched plate and one stainless steel control plate. They could best be described as mildly oxidized, severely oxidize, not oxidized, and stainless steel plates respectively. The two oxidized plates where compared with known standards of oxidation states found from an artist group's website (Copper Weathering and Patina Chart for Weathervanes, 2007). The 30 second/mildly oxidized plate closely resembled a four month weathered copper plate. The 5 minute/severely oxidized plate resembled the example for 3 years. This is the furthest in time heat can oxidize copper to known oxidation states as the known green color is representative of a sulfide compound that gathers in trace amounts over years of exposure to water and air (Ibid). One plate was heated well past 5 minutes but the color was no different than the five minute plate.

Heat oxidizing copper plates occurs quickly and is highly unpredictable. The goal was to heat the copper to match known examples of copper oxidation at different places in time – this goal proved to be unrealistic. The color change of the copper during the heating was markedly varied. The better option was to use to simply time how long the copper was heated. Copper's astonishing conductivity to heat became a factor. Originally the copper was heated held upright in a vice. It was noted that where the copper met the vice, and a full centimeter above, was not changing color whatsoever – the heat was being transferred to the vice which became markedly hot. The copper was then heated while lying on concrete. Copper attained for this study was in 4 inch by 6 inch plates. They came from Takach Press, an etching company, and were 99% pure.

The industry standard for medical grade copper is 90/10 copper/nickel (A. Estelle, Copper Development Association, personal communication, February 10, 2014). This composition is thought to withhold better and take longer to oxidize. This study focused on pure copper to understand what effect copper oxide had on bacteria rather than testing the performance of different alloys. The 4 by 6 inch plate conducted the heat away from the propane torch too quickly, to uniformly oxidize the plate. The plates where then cut to 4 inch by 3 inch plates. The unpredictability of copper and heat carried into the sterilization of the plates for testing. Autoclaving the plates created a completely random coloring, with colors that normally would suggest different ages, scattered across the plate. The pattern resembled water marks. To maintain a controlled state of oxidation 70% alcohol was used to sterilize the plates.

Bacteria Selection

The bacteria selected were based on their prevalence in healthcare. *Staphylococcus aureus* was chosen for it frequency as a hospital acquired infection (Bauman, 2011, and others). *Enterococcus faecalis* was chosen for the recent development and prevalence of vancomycin resistant strains (Nikaido, 2009). *Pseudomonas aeruginosa* was chosen for is natural resistance to antimicrobial agents and its ubiquity in healthcare settings (Bauman, 2011). *Clostridium perfringens* was chosen for its ubiquitous cousin *Clostridium difficile* and its ability to form spores (Bauman, 2011). None of these strains had known antibiotic resistance like those often seen in healthcare. So why then were they chosen over the resistant strains? Antibiotic resistance is of little relevance when bacteria are being tested on copper surfaces. Copper's known primary antimicrobial actions involve the bacterial membrane destruction and ion transport chain disruption (Grass 2011 et al., Varghese et al., 2013).Antibiotic resistance comes from plasmids that code for antibiotic altering enzymes and antibiotic efflux pumps (Nikaido, 2009). Plasmids do not alter the basic phospholipid structure of bacterial membranes or their methods of producing energy via ion transport.

Bacterial Inoculation of the Copper Plates

Many methods of inoculating copper plates have been used to test copper's antimicrobial effects. Bacteria impregnated agar sheets offer a more precise method of exposing bacteria to various surfaces. For this study, however, bacteria were applied via sterile swab from nutrient broth. This method, though it is less precise, offers a worst-case scenario example of bacterial contamination in a healthcare setting. A sneeze from a patient with an upper respiratory infection has the potential to deposit a large bacterial load onto a surface, as would contamination of a surface by infected bodily secretions. This method is also much simpler design.

A swab from nutrient broth inoculated the plates. A new swab was then used to sample the contaminated plates and put into sterile nutrient broth at different time periods – 10, 30, 60, and 120 minutes. The samples were then placed in nutrient broth and incubated for 48 hours. At this time length the samples could only truly be defined as either positive or negative for growth. All transfers were done under a Laminar Flow Hood after 48 hours of UV sterilization. Fluid thioglycolate media was used for *C. perfringens* to support anaerobic growth.

Results

Table 3 shows the results of the samples taken of either positive or negative for growth. Table 4 shows a visual interpretation of the samples as heavy growth, moderate growth, or scant growth. The *P. aeruginosa* sample also has a description of bacterial pigment production. The results in Table 4 would need to be confirmed by serial dilution to be scientifically sound. They are presented here to show a likely correlation between bacterial exposure time and bacterial destruction – visually there was an obvious decrease in growth related to length of exposure.

The results show the known antimicrobial benefits of copper against *S. aureus* and *E. faecalis*. For both of these bacteria, the oxidized copper showed an increased antimicrobial effect. When compared to the unaltered copper plate, oxidized copper plate destroyed *E. faecalis* at a faster rate. The oxidized copper plates destroyed all bacteria within 30 minutes – at least half the time it took for the unaltered copper plate. Only the oxidized copper plates had an antimicrobial effect against *S. aureus*. The oxidized copper exerted its full effect within one hour. None of the samples of *P. aeruginosa* or *C. perfringens* were negative for growth. None of the samples from the stainless steel control were negative for growth except for one anomaly with *C. perfringens* (to be negative for growth all bacteria would have had to be destroyed leaving nothing left for subsequent samples, it is likely the inoculated swab was misplaced and a sterile one put in the broth).

Discussion

The purpose of this study was to determine if there was decrease in the antimicrobial effects of copper in relation to degree of oxidation. The results showed that oxidized copper outperformed the control copper with two of the selected bacteria. In regards to the possible performance of copper in healthcare facilities this is encouraging news. This study shows that once copper is installed it will most likely retain its antimicrobial effects for years without any special maintenance. It would actually become more effective as time passed.

When discussing the antimicrobial effects of copper one is essentially discussing the action of copper ions and how they affect bacteria. Results from this study would suggest, from a pure chemical standpoint that oxidized copper has more available free copper ions to interact with bacteria. What then would be the point in adding nickel to copper? Adding nickel stabilizes

S. aureus	**OS**	**10 min**	**30 min**	**60 min**	**120 min**
P1	+	+	+	+	+
P2	+	+	+	+	+
P3	+	+	+	-	-
P4	+	+	+	-	-
P. aeruginosa	**OS**	**10 min**	**30 min**	**60 min**	**120 min**
P1	+	+	+	+	+
P2	+	+	+	+	+
P3	+	+	+	+	+
P4	+	+	+	+	+
C. perfringens	**OS**	**10 min**	**30 min**	**60 min**	**120 min**
P1	+	+	+	+	+
P2	+	+	+	-	+
P3	+	+	+	+	+
P4	+	+	+	+	+
E. faecalis	**OS**	**10 min**	**30 min**	**60 min**	**120 min**
P1	+	+	+	+	-
P2	+	+	+	+	+
P3	+	+	-	-	-
P4	+	+	-	-	-

Table 3 – Results in terms of positive (+) or negative (-) for growth. P1 = Control copper plate with no oxidation; P2 = Stainless Steel control; P3 = Copper plate with moderate oxidation after 30 seconds heat exposure; P4 = Copper plate with severe oxidation after 5 minutes heat exposure; OS = the original inoculating swab, cultured as a control to confirm actual inoculation

S. aureus	**OS**	**10 min**	**30 min**	**60 min**	**120 min**
P1	Moderate	Heavy	Heavy	Moderate	Scant
P2	Moderate	Heavy	Heavy	Moderate	Moderate
P3	Moderate	Heavy	Heavy	Negative	Negative
P4	Moderate	Moderate	Moderate	Negative	Negative
P. aeruginosa	**OS**	**10 min**	**30 min**	**60 min**	**120 min**
P1	Heavy-Green	Moderate	Scant	Scant	Scant
P2	Heavy-Green	Heavy-Green	Heavy-Green	Heavy	Heavy
P3	Heavy-Green	Heavy	Heavy	Moderate	Moderate
P4	Heavy-Green	Heavy	Heavy	Moderate	Moderate

C. perfringens	**OS**	**10 min**	**30 min**	**60 min**	**120 min**
P1	Heavy	Heavy	Moderate	Scant	Moderate
P2	Heavy	Heavy	Moderate	Negative*	Scant
P3	Heavy	Heavy	Moderate	Scant	Moderate
P4	Heavy	Heavy	Moderate	Scant	Moderate
E. faecalis	**OS**	**10 min**	**30 min**	**60 min**	**120 min**
P1	Heavy	Moderate	Moderate	Negative	Negative
P2	Heavy	Heavy	Scant	Scant	Scant
P3	Heavy	Heavy	Negative	Negative	Negative
P4	Heavy	Heavy	Negative	Negative	Negative

Table 4 – Visual interpretation of growth as heavy, moderate, scant or negative growth. Also included is a comment on color for Pseudomonas where applicable.

copper as evidenced by nickel's effect in slowing down the copper oxidation process. Copper oxide in this study proved to be more antimicrobial. However, the copper nickel alloys studied by the Copper Development Association for EPA's certification of copper as an antimicrobial surface did show the same bactericidal effect as pure copper. This would highly suggest that the copper nickel alloy still allowed copper ions to interact with bacterial membranes. It could, however, slow copper's full antimicrobial effect that oxidation allows. When compared with the artist samples the plate that was oxidized by propane torch it appeared to be aged to three to five years. The results of this study could not completely predict how copper would work after that. There may eventually be a cutoff for the antimicrobial effects of copper after several decades. In that case adding nickel would be prudent. Slowing down the oxidation process would likely be wise in that it would ensure copper's antimicrobial effects for much longer than pure copper plate.

Further testing would be prudent to confirm the results in Table 4. The samples showed a reduction in growth; the longer the bacteria were exposed to copper. A quantitative approach would most likely show that the copper did have an effect on *P. aeruginosa* and *C. perfringens*. Other studies have found *P. aeruginosa* and *C. difficile* to be susceptible to the antimicrobial effects of copper (Gould et al., 2009, Wheeldon et al., 2008). The samples of *P. aeruginosa* that were on the copper for more than 10 minutes did not show any of the characteristic green pyoverdin pigment, lending to the concept that there was inhibition related to copper exposure. There was a consistent shift from heavy growth to scant growth of *S. aureus*, *P. aeruginosa*, and *E. faecalis* on all of the copper plates.

Copper has been demonstrated in other studies to have a bactericidal effect on *S. aureus* and *P. aeruginosa* (Varghese et al., 2013). Why then did these bacteria continue to have positive results? There are several explanations for this seeming anomaly. Inoculating surfaces from broth introduces a massive bacterial load in liquid form. It is possible that some bacteria survived on the plate because they never came in contact with the plate. Avoiding contact with the plate might have been accomplished because the bacteria were in a liquid media. The copper was visibly wet for some time after the inoculation, possibly providing sanctuary for the bacteria from the copper surface. If visualizing growth in a liquid medium was a reliable quantitative approach, this study would have shown conclusively that copper is antimicrobial in all forms. Despite these limitations this study proved conclusively that oxidizing copper does not decrease its antimicrobial effects. On the contrary, it increases copper's antimicrobial effect. It also shows once again that copper could be a valuable asset in preventing hospital acquired infections and that stainless steel is not.

Conclusions

Copper currently is an untapped resource for decreasing the rates of hospital acquired infections. Where there are many interventions for lowering the rate of these infections, copper is unique in many ways. Copper yields a constant antimicrobial effect – it works at all times. After installation of copper surfaces, no other intervention is required; it will simply provide a constant decrease in bacterial load. Unlike hand-washing campaigns and increasing the use of sterile technique, where the actions must be repeated over and over to sustain the desired effect, copper can be left alone and function for many years. As the oxidation study showed, copper not only retains its antimicrobial effects after oxidizing, its antimicrobial effect is increased. This makes copper a long term investment that could continue to decrease bacterial load, and thereby reduce the rate of HAIs, for many years after its installation. The five minute plate was oxidized to at least what could be expected in three years, gauging it by sight alone. It is likely that that estimate is very conservative. Adding nickel to the copper could maintain its efficacy by many more years, by preventing the possible point, where age may affect copper's antimicrobial properties. Given the massive oxidation state of the five minute plate however, that age may not be reached for many decades even without adding nickel.

The benefits of copper's antimicrobial effects were made clear by the Salgado study. There were no changes in policy, no new procedures, simply copper added to ICU rooms. The result was an over fifty percent reduction in HAIs with each room preventing two infections a year. The cost/benefit analysis revealed that upgrading a standard medical/surgical room, with most of the Salgado surfaces and several others would cost $3,439.95. Using the Hassan figure of $10,375 per HAI, the upgrade would more than pay for itself by preventing just one infection. The projected cost in this study of 2.6 million to upgrade an entire hospital may seem substantial, and may even be low given the vast number of surfaces found outside of patient rooms, but when compared to what copper can save it is very realistic. The estimates from the Douglas report and the Hospital Directory, show that a large tertiary care center could payout over 4.4 million dollars a year in HAIs. If copper decreased this cost by half, as seen in the Salgado study, then the entire cost to upgrade a hospital could be justified in just over a year.

From a pure nursing standpoint, the benefit of copper is clear if it prevents even one HAI. Hospital acquired infections are not nearly as expensive, as they are stressful to the patient. What a patient experiences from the diagnosis of a hospital acquired infection, can hardly be quantified in dollars and cents. It is often that one diagnosis, which leads a patient to lose faith in their healthcare team. With the rates of HAIs increasing, and the ever increasing danger of resistant strains of bacteria, it is time to be more proactive in preventing these infections. Hand washing is only effective when done constantly and correctly. Stainless steel can act as a reservoir for bacteria even when cleaned with due diligence. Copper, however, works constantly, consistently and without active intervention by staff, visitor or patient, and can do so for many years. One must also keep in mind that preventing one HAI could save a life. Any preventable death is tragic. If we can avoid such tragedy with any intervention it is our duty.

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