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A Comparison of Corrosion Potential, Installation, Maintenance, and Anti-Microbial Efficacy: Copper Combined with a Polymer Matrix or Stainless Steel for Use in a Hospital Setting

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Introduction

According to Boev and Kiss in their article, "Hospital-Acquired Infections," hospital-acquired infections (HAIs), also known as nosocomial infections, are currently the leading cause of deaths and disability in hospitalized patients (2017, p. 51), so they cost both patients and hospitals a lot of money. As of right now, QualityNet reports on their "Scoring Methodology" page that Obamacare's Hospital-Acquired Condition (HAC) Reduction Program requires for hospitals with high cases of HACs to be subject to a reduction of Medicare payments (n.d.). The World Health Organization explains in *Prevention of hospital-acquired infections: A practical guide, 2nd edition* that HAIs can be acquired through environmental infection, wherein one acquires the infection from inanimate objects, substances, or surfaces that have been contaminated by a human source (World Health Organization, 2002, p. 10). Because environmental infection can be caused by surface contact, by installing antimicrobial surfaces, hospitals can reduce the rate of HAIs due to environmental infection.

The contact killing mechanism of copper requires a direct interaction between copper ions and the bacterial cell that is to be targeted. Mitchell stated in her blog titled, "Hospital surfaces: The good, the bad...and the ugly," that copper's microbicidal behavior results from it oxidizing in contact with bacteria along with the combined effect of releasing free radicals, which causes the deterioration and eventually breakage of the cell wall (2014). Dan, Ni, Xu, Xiong, and Xiong (2005) added from their journal article, "Microstructure and antibacterial properties of American Iron and Steel Institute (AISI) 420 stainless steel implanted by copper ions," that as copper ions flood into the cell, the cell membrane of the bacteria is damaged (p. 100). Dan et al. (2005) continued that once inside, copper can: cause the bacterial cell to degenerate because it can combine with protease, solidify protein structures, and alter enzyme function (p. 100). As O'Gorman and Humphreys (2012) noted in their article, "Application of copper to prevent and control infection. Where are we now?," bacterial DNA degradation also occurs at some point, but the investigations into copper's biocidal behavior is still ongoing (p. 218). What is determined is that copper ion release is required to interfere with bacterial functions, given that the bacterial cell walls are broken down and copper ions are absorbed into the cell.

While both copper embedded in a polymer matrix and copper-implanted stainless steel have received new attention, the two have not been compared. This paper will attempt to analyze the comparison of copper ions implanted into a polymer matrix versus copper ions implanted into stainless steel for the purpose of containing the spread of HAIs in hospitals with the expectation that copper-embedded polymer matrices are a better alternative than copper-implanted stainless-steel surfaces due to polymer's versatility and low price, and its ability to be modified to become a better antimicrobial surface.

Corrosion

Airey and Verran (2007) noted in their journal article, "Potential use of copper as a hygienic surface; problems associated with cumulative soiling and cleaning," that, currently, most hospitals use stainless steel because it is "stable and inert" (p. 272). According to the Washington Suburban Sanitary Commission on their *Copper Pitting Corrosion FAQs* page, pure copper naturally experiences pitting corrosion, which occurs excessively in a small area (n.d., Explain the difference section). Moreover, Airey and Verran (2007) found that more than two soiling/cleaning cycles on the pure copper surface that they examined for antibacterial properties caused the "layers of the BSA [bovine serum album]-bacteria soil to bond more strongly to the surface, increasing its resistance to cleaning" (p. 276), unlike the stainless-steel surfaces that they examined, which demonstrated decreasing soil coverage percentages as the number of soiling/cleaning cycles increased (p. 274). Airey and Verran (2007) concluded that the cleaning products reacted with the copper (p. 277); moreover, the build-up of cells for the copper surfaces was found in isolated areas (Airey and Verran, 2007, p. 274), which is evidence for pitting corrosion. Thus, it may be more effective to use copper-bearing materials, which are corrosion resistant, to prevent the build-up of cells due to pitting corrosion and allow for efficient cleaning.

Implanting copper into stainless steel is an alternative to pure copper. Dan et al. (2005) found that "the Cu-implanted specimens with and without annealing treatment [1.9 ± 0.1% pitting corrosion area and 1.8 ± 0.1% pitting corrosion area, respectively] have a corrosion resistance equivalent to that of common AISI 420 SS [2.0 ± 0.1% pitting corrosion area]" (p. 100). Since implanting copper into stainless steel does not affect the corrosion resistance of the stainless steel, itself, bacteria would not adhere to the surface in multiple layers, allowing for the surface to be properly cleaned. Dan et al. (2005) noted that annealing treatment always allowed the specimens to maintain good corrosion resistance (p. 100) and led to the formation of copper compounds on the surface layer; this resulted in the specimens with the compounds to exhibit higher antibacterial activity than the specimens with a higher copper content (p. 98). This copper contact killing mechanism was more pronounced than if the specimens merely contained copper, which could not be released as easily. Thus, surface layers containing copper or its compounds are necessary for increased antibacterial performance.

However, it is interesting to note that not all copper compounds give efficiency to antimicrobial surfaces. According to Hans, Erbe, Mathews, Chen, Solioz, and Mücklich (2013) in their article, "Role of copper oxides in contact killing of bacteria," when copper corrodes in wet plating conditions, it forms a more stable compound called copper (II) oxide; this compound prevents release of copper ions, which are necessary for antibacterial activity (p. 16164). On the other hand, Hans et al. (2013) observed that when copper corrodes in air, the compound it forms (copper (I) oxide) does not seem to prevent the loss of copper's antibacterial properties (p.

16164). As copper (I) oxide does not demonstrate the level of stability of copper (II) oxide, its formation on the surfaces may actually increase the antimicrobial effects of copper contact killing. Additionally, Hans et al. (2013) identified that the copper (II) oxide layer had a roughness of 671 ± 234 nm compared to the copper (I) oxide layer, which had a smaller roughness of 22 ± 6 nm (p. 16163). Thus, making the surface smoother keeps corrosion resistance and antimicrobial efficiency, as further evidenced by Airey and Verran's (2007) discovery that the Rimex mirror-finished stainless steel, which had a 10-fold lower surface roughness value than pure copper, retained the lowest levels of bacteria soil (p. 274).

Certain types of polymers are also corrosion resistant, especially polyolefins, which include polyethylene (high-density polyethylene (HDPE), low-density polyethylene (LDPE), ultra-high-molecular-weight Polyethylene (UHMW-PE)) and polypropylene, polyvinyl chlorides (PVC), and fluoropolymers, which include polytetrafluoroethylene (PTFE), fluorinated ethylene propylene (FEP), perfluoroalkoxy alkanes (PFA), polyvinylidene difluoride (PVDF), polychlorotrifluoroethylene (PCTFE), ethylene chlorotrifluoroethylene (ECTFE), ethylene tetrafluoroethylene ETFE, etc. (Professional Plastics, n.d.). However, the Healthier Hospitals Organization is pushing for PVC reduction in their Safer Chemicals Challenge (2015, List of medical products section) due to the fact that the production of PVC employs known human carcinogens, such as vinyl chloride monomer (VCM) (Healthier Hospitals Organization, n.d., p. 4), so the use of polyolefins or fluoropolymers is more suitable for hospital use. Overall, these composites of either stainless steel or polymers will allow for copper ion release without degradation of the matrix itself.

Copper Ion Release

As established in the introduction, copper ion release is required for the antimicrobial function of copper-bearing surfaces. Copper ion release, in turn, is more affected by the concentration of surface layer copper. Thus, increased copper ion release allows for the surface to be more efficient as an antimicrobial surface, as supported by a study conducted by Palza, Delgado, and Pinochet in their article, "Improving the metal ion release from nanoparticles embedded in a polypropylene matrix for antimicrobial applications" (2014, p. [41232]2).

While O'Gorman and Humphreys (2012) determined that alloys must contain at least 55% of copper in order for there to be significant biocidal behavior (p. 219), it seems that few studies have examined copper ion release rates for dry conditions. However, Hans et al. (2013) did find that the antibacterial behavior of copper (I) oxide—which is formed in dry conditions—is similar to that of pure copper (p. 16164). Hans et al. (2013) cited copper (I) oxide's higher copper ion release rates of 0.30 ± 0.09 nmol/(min cm^2) for Cu_2O in PBS and 14.34 ± 2.23 nmol/(min cm^2) for Cu_2O in Tris-Cl as compared to copper (II) oxide's copper ion release rates of 0.16 ± 0.09 nmol/(min cm^2) for CuO in PBS and 5.01 ± 2.49 nmol/(min cm^2) for CuO in Tris-Cl (p. 16164). Hans et al. (2013) added that copper (I) ions are more toxic to bacteria than copper (II) ions (p. 16165). Nonetheless, the study conducted by Hans et al. examined the antibacterial efficiency of copper compounds in solution despite the formation of copper (I) oxide in dry conditions. Consequently, more studies need to be conducted which can measure the antibacterial efficiency of copper-containing surfaces in dry conditions, as one would expect to see dry surfaces coming in contact with humans in hospitals; wet surfaces would be touched while wearing gloves, which would most likely be discarded before it can become a contaminant like other surfaces.

Be that as it may, Dan et al. (2005) argued that copper in stainless steel must be in the form of Cu-rich phase or Cu-containing phase which distributes homogeneously in order for the copper to exhibit antibacterial activity, which it does not exhibit when it is in the form of a solute in a solid solution (pp. 97-98). Thus, the copper must be differentiable from the stainless steel in order for the ions to be released efficiently. As for polymers, Palza, Quijada, and Delgado (2015) concluded in their article, “Antimicrobial polymer composites with copper micro- and nanoparticles: Effect of particle size and polymer matrix,” that using a polymer matrix that was hydrophilic or that was a low crystalline matrix increased copper ion release (p. 378). Thus, the matrix being used is also a determinant in copper ion release.

Copper ion release can also be increased in polymers. Palza et al. (2014) listed other procedures which increased copper ion release rates from the polypropylene composites, including improving the melt mixing conditions, such as by using double melt mixing or by using the dissolution method, using a compatibilizer, or by using a polymer matrix with a higher molecular weight (p. [41232]7). Therefore, the process of copper implantation is essential to increasing copper ion release rates.

Palza et al. (2014) found that they could increase the copper ion release from a polypropylene composite up to 80 $\mu g/L/cm^2$ after ten days, provided that the polypropylene composite had been embedded with either copper nanoparticles pre-dispersed in ethanol or with functionalized copper nanoparticles (p. [41232]7). In a separate study by Palza et al. (2015), the researchers found that polypropylene with a 5% copper nanoparticle filler content exhibited the highest copper (II) ion release rate of over 1.3 $\mu g/mL*cm^2$, which was more than either the polypropylene composites with a 1% copper nanoparticle filler content or with the 5% copper microparticle filler content (p. 372). Moreover, Delgado, Quijada, Palma, and Palza (2011) discovered in their article, “Polypropylene with embedded copper metal or copper oxide nanoparticles as a novel plastic antimicrobial agent,” that embedding polypropylene with copper oxide nanoparticles rather than copper metal nanoparticles has an even greater copper ion release (p. 54). Hence, along with amount of copper particles being incorporated into the polymer or stainless-steel matrices, the very particles being implanted can be changed, in terms of size and attachment, to additional components in order to improve copper ion release.

Ways to increase copper ion release in both copper-bearing stainless steel and copper-embedded polymer matrices are still being investigated. Because this area requires further research, no conclusions can be drawn about which of the two materials can yield a greater copper ion release. However, it seems that in both materials, copper nanoparticles allow for the greatest copper ion release, provided that the particles are dispersed throughout the polymer matrix or stainless steel.

Reaction with Cleaning Products

Airey and Verran (2007) concluded that the cleaning products, 1% sodium hypochlorite and 70% industrial methylated spirit—both of which are commonly used in hospitals—reacted with the copper (p. 277). This is further supported by the researchers, Mikolay, Huggett, Tikana, Grass, Braun, and Nies, in a 2010 study titled, “Survival of Bacteria on Metallic Copper Surfaces in A Hospital Trial,” who conjectured that the glucoprotamin in their cleaning solution may have created a layer in between the metallic copper surface and the bacteria they were examining, which reduced the biocidal effects of copper (O’Gorman & Humphreys, 2012, p. 222). Accordingly, if copper-bearing surfaces are installed, hospital administrations must be careful not to employ cleaning products which either cause corrosion or prevent copper ions from interacting with bacterial cells.

Hospital infection control is done through both detergents, which are chiefly used as cleaning agents, and disinfectants, which are stronger antimicrobial agents. Accini wrote in her article, "Top ten disinfectants to control HAIs," that disinfectants are generally broken down into three levels: low, intermediate, and high (2012). Accini further broke down commonly used high-level disinfectants, which includes formaldehyde, commonly used intermediate-level disinfectants, which includes sodium hypochlorite, and commonly used low-level disinfectants, which include phenols and quaternary ammonium compounds (2012). Graco Inc. (2013) reported in its *Chemical Compatibility Guide* that Stainless Steel 316 exhibits corrosion resistance against formaldehyde and sodium hypochlorite, while Stainless Steel 304 exhibits corrosion resistance against phenols and quaternary ammonium salts. Graco Inc. (2013) also detailed that UHMW Polyethylene, but not polypropylene, also exhibits corrosion resistance against formaldehyde and sodium hypochlorite, while PTFE exhibits corrosion resistance against phenols and quaternary ammonium salts. For most cases of daily use and minor cases, hospital administrations would be more inclined to use low-level disinfectants. As a result, copper-bearing Stainless Steel 304 or copper-embedded PTFE should be used in areas which are more likely to be cleaned daily, whereas copper-bearing Stainless Steel 316 or copper-embedded UHMW Polyethylene should be used in areas which require more potent cleaning procedures and products.

Currently, copper/polymer composites are being tested in real-world settings. For example, Gauding (2016) discussed a 10-month clinical trial in his article, "World's largest clinical trial on copper a success at Sentara," which showed positive results in terms of HAI prevention and control for copper-infused hard products provided by EOS Surfaces, LLC and copper-infused linens provided by Cupron, Inc. EOS Surfaces, LLC, claims that "disinfectants will disinfect the surface, will not affect the efficacy of EOS^{Cu}, and generally contain one of the following: alcohols, bleaches, quaternary ammonium, ammonium chloride (use in normal dilute formulations), phenol and ammonia (rarely used organic materials)" (EOS Surfaces, LLC., 2016). This list includes both intermediate-level and low-level cleaning agents, so these composite surfaces are more suited to use in areas of daily cleaning.

The CDC recommends that a detergent be used before a disinfectant; not doing so reduces the effectiveness of the disinfectant (2008, Cleaning section). The CDC reported that for instrument cleaning, enzymatic cleaners, alkaline-based cleaners, and hydrogen peroxide-based cleaners are all currently used as detergents, adding that commonly used detergents were of neutral or near-neutral pH (2008, Cleaning section). However, the CDC also cautioned that alkaline-based cleaners can be corrosive (2008, Cleaning section). Alfa and Jackson explained in their article, "A new hydrogen peroxide--based medical-device detergent with germicidal properties: comparison with enzymatic cleaners," that hydrogen peroxide "can be corrosive to aluminum, copper, brass, or zinc" (2001, p. 174). Enzymatic cleaners, when prepared properly, are non-corrosive and do not cause damage to softer surfaces, such as rubber (Metrex Research, LLC., n.d.), so they will not cause damage to polymers, as well. Thus, enzymatic cleaners are the best option for use as a detergent when copper-embedded polymer surfaces are used.

Polypropylene and polyethylene generally have a chemical resistance higher than that of metal, which includes resistance to alkaline cleaners (Orion Fittings, Inc., n.d.; Teague, n.d.). Mireles, Dayan, Massicotte, Dagher, and Yahia (2016) found in their article, "Interactions of active compounds of disinfectants on metallic and polymeric hospital surfaces," that disinfectants, such as sodium hypochlorite and hydrogen peroxide, were decidedly more aggressive on metals, including stainless steel, than on polymeric surfaces (p. 46). Moreover, EOS Surfaces, LLC claimed that the installation of EOS^{Cu} need not change current hospital cleaning procedures (n.d., Frequently Asked Questions About EOS^{cu} section), with the exception of installing soap dispenser catches above the surfaces to prevent coating the surfaces (EOS Surfaces, LLC., 2016). Consequently, it may be easier for hospital administrations to implement copper-embedded polymer surfaces so that changing cleaning procedures need not be drastic.

Regardless, O'Gorman and Humphreys (2012) asserted that the use of antibacterial surfaces should act only as a supplement to standard infection control and prevention measures, which involve hand hygiene and routine cleaning (p. 222). Neither stainless steel nor polymer matrices will cause an extreme burden on revising hospital cleaning practices, provided that the hospital uses material fit for their cleaning procedures. Yet, based on the results from the study conducted by Mireles et al. (2016), polymers are more durable than stainless steel against cleaning, so using polymer-based surfaces will be more beneficial to hospitals in the long-run.

Applications

Copper-implanted surfaces can be implemented in a variety of places. For example, EOS Surfaces, LLC claimed that their copper/acrylic/polyester solid surfaces can be used on any horizontal or vertical surface if manufactured as a slab or a sheet; it can also be manufactured into molded products, such as "bed rail kits, sinks, vanities, armrests, grab rails, and virtually any other customizable shape" (n.d.). Mitchell explained that stainless steel is mainly found on operating trays, kitchen surfaces, sinks, shelves/racks, and door handles (2017).

Under extreme circumstances, polymers are not durable, and stainless steel must be used. For example, Marlin Steel stated that stainless steel is better for use in instrument trays, which have to be subject to extreme temperatures (2017). The Stainless-Steel Information Center affirmed stainless steel can be used in temperatures up to 1700 degrees Fahrenheit (n.d.), while IPS Flow Systems reported in 2012 that polypropylene's maximum operating temperature is 194 degrees Fahrenheit (p. 252). According to the CDC, "the two common steam-sterilizing temperatures are 121°C (250°F) and 132°C (270°F)" (U.S. Department of Health and Human Services, 2008, p. 58), both of which are greater than 194 degrees Fahrenheit. Therefore, only stainless steel can be applied in surfaces which require steam-sterilizing.

Furthermore, the Marlin Steel blog explained that an instrument tray with porous polymer would display discoloration from absorbed contaminants, so it would need to be discarded sooner than a comparable instrument tray with stainless steel, which can be electropolished to be smooth and which has an oxide layer that repels most contaminants (2017). If the surface absorbs contaminants, then that would defeat the purpose of installing the antimicrobial surface to prevent the spread of HAIs, part of which is achieved through cleanliness.

Some physical settings in hospitals require the use of polymer surfaces. For example, Connecticut Plastics asserted that using metals near the MRI machine may interfere with the function of the magnet (n.d.). Following this reasoning, places near electromagnetic equipment may require polymer surfaces, as plastics are electrical insulators and are not attracted to magnets. Polymers would also be more suited for installation in areas near patients, such as in bed rails or food trays, as they are also thermal insulators. Hospitals are generally kept cold (Anytime Heating and Cooling, Inc., 2017), so metals, being thermal conductors, would feel even colder to the touch in the cold hospital environment, which may be uncomfortable for the patient.

Apart from surfaces which require exposure to extreme heat, polymers can be used in almost all other places, provided that they are not porous enough to absorb contaminants. Here, it is important to note that, according to EOS Surfaces, LLC., the polymer composite surfaces used in the 10-month clinical trial at the Sentara Leigh Hospital were "composed of [a] non-porous homogenous blend of polyester and acrylic alloys and fillers" (ĒOS Solid Surfaces, 2008). Thus, polymer surfaces can indeed be modified to prevent contaminant absorption, making polymer surfaces more effective for use in hospitals, as they would not have to be discarded due to dirtying. Therefore, polymers, including copper-polymer composite surfaces, demonstrate a higher versatility than stainless steel.

Associated Costs and the Necessity to Spend

Currently, EOS Surfaces, LLC. requires for their surfaces to be installed by their certified fabricators (n.d., Who can fabricate and install EOS^{cu} section). Another company called Olin Brass produces CuVerro, which are metal sheets— not stainless steel —implanted with copper (Olin Brass, 2012a, 2012b), and these products, too, have affiliate companies which distribute and install the copper-bearing surfaces (CuVerro, n.d., Where can I purchase products section). Hence, since the costs of installing the surfaces is reliant upon the company and its approved affiliates, these costs to install the surfaces remain consistent among the installers. These prices also should not differ very much between EOS Surfaces, LLC. and Olin Brass because both would require approximately the same amount of labor.

Therefore, one of the main differences in pricing would come from the pricing of the matrices. According to MetalMiner, the price of 304 Stainless Steel is $1.62 per pound (2017). According to the Plastic News website (http://www.plasticsnews.com/resin), the price of polypropylene ranges between $0.81-$0.83 per pound as of December 4, 2017, the price of HDPE ranges between $0.87-$0.89 per pound as of October 30, 2017, and the price of UHMW-PE ranges between $1.36-$1.46 per pound as of February 14, 2011. Thus, using polymer matrices would cost less than using stainless steel matrices.

Transportation from the factories which create the copper-bearing polymer sheets to the hospitals to be installed also adds to the cost to install the surfaces. Smith explained that transportation costs are calculated by considering weight of the commodity being transported (n.d.). Aqua-calc reported that the weight of polypropylene is 0.494 ounces per cubic inch (2017), while Benjamin Steel reported that the weight of stainless steel is 0.2904 pounds per cubic inch (2011), which is 4.6464 ounces per cubic inch. Because the weight of polymers would not be as much as the weight of the same amount of stainless steel, transportation costs for stainless steel would be more than the transportation costs for polypropylene.

Also, the efficacy of copper/polymer composites has already been proven in a clinical setting, so hospital administrations would be taking less risk by installing copper/polymer composites. A study conducted by Sifri, Burke, and Enfield (2016) showed results that the wing at the Norfolk Sentara Leigh Hospital with the EOS^{Cu} surfaces had a 68% reduction in HAIs due to multidrug-resistant organism relative to the baseline for the duration of 25.5 months (p. 1565). EOS Surfaces, LLC. also found an 81% microbial burden reduction after 30 hours on copper oxide-impregnated self-sanitizing surfaces (SSSCu) in a separate trial at the Olin E. Teague Veterans' Medical Center (EOS Surfaces, LLC., n.d., Initial Study Results section); the journal article by Coppin, Villamaria, Williams, Copeland, Zeber, and Jinadatha (2017) further stated in their article, "Self-sanitizing copper-impregnated surfaces for bioburden reduction in patient rooms," that the mean aerobic bacterial colony counts for non-SSSCu surfaces was 98.2 colonyforming units (CFU)/25 cm^2 and for SSSCu surfaces was 18.9 CFU/25 cm^2 (p. 693). More studies involving the EOS surfaces are ongoing (Gauding, 2016), so hospital administrations will have even more evidence of the success of copper-embedded polymer matrices before deciding to implement the surfaces into hospitals. According to Hinsa-Leasure, Nartey, Vaverka, and Schmidt, the efficacy of copper-bearing metal surfaces, specifically CuVerro has also been established (2016); however, there are no clinical trials specific for copper-bearing stainless steel, as CuVerro surfaces are not based on stainless steel (Olin Brass, 2012a, 2012b). Thus, it would be a greater risk to hospital administrations to currently install copper-bearing stainless steel.

Furthermore, according to the chief executive of Grinnell Regional Medical Center in Iowa, installing copper-bearing surfaces may cost up to 15-20 percent more than installing stainless steel surfaces; however, in the long-run, installing these surfaces—which is about $5,000—costs less than the added amount that hospitals pay for every patient's infection—which is about $43,000 (Sun, 2015). By saving $38,000 for every patient who may have potentially become infected with an HAI, hospital administrations can divert their funding to areas that they deem fit for smooth operation of their hospital.

Resistance to Copper

Like multidrug-resistant organisms which demonstrate antibiotic resistance through gene mutations, *E. coli* and other Enterobacteriaceae also have gene clusters, called the Copper Homeostasis And Silver Resistance Island (CHASRI), that confer resistance against copper ions, according to the article, "Evolution of a heavy metal homeostasis/resistance island reflects increasing copper stress in Enterobacteria," by Staehlin, Gibbons, Rokas, O'Halloran, and Slot (2016, p. 812). This gene cluster contains the *pco* and *cus* genes (Staehlin et al., 2016, p. 812), which can be horizontally transferred (Staehlin et al., 2016, p. 822), a process made easier in a hospital environment due to the bacteria being repeatedly exposed to copper ions, resulting in only bacteria with the resistance genes to survive and pass their genes.

However, Grass, Rensing, and Solioz (2011) argued in their article, "Metallic Copper as an Antimicrobial Surface," that widespread bacterial resistance to copper through contact killing is unlikely due to the following: plasmid DNA is completely degraded after contact killing, which prevents horizontal transfer; contact killing is rapid and cells do not divide on copper surfaces, which prevents vertical transfer; and no bacteria are known to be fully resistant to contact killing despite the fact that human civilizations have been using copper for its antimicrobial properties for thousands of years (pp. 1545-1546). Thus, copper-based antimicrobial surfaces are a lasting solution against nosocomial infection-causing bacteria.

Conclusion

Given the evidence, copper implanted into a polymer matrix would function as a better antimicrobial hard composite surface for a hospital environment than copper implanted into stainless steel because polymer surfaces do not corrode as easily as steel surfaces, especially in reaction to hospital cleaning products. Polymers are also more versatile and less expensive, resulting in the reduction of the spread of hospital-acquired infections. Nonetheless, implementing these surfaces should not be a substitute for current cleaning policies; rather, these surfaces should act as a supplement to hospital cleaning procedures.

While current studies are examining the antibacterial efficacy of copper/polymer composites in real-world settings, and initial studies have shown success, there is a lack of such studies for copper-implanted stainless steel. Thus, more research needs to be done for copper-implanted stainless steel in a clinical setting. Perhaps the best antimicrobial surface given available research is a non-porous polymer hard composite, which demonstrates hydrophilic behavior, low crystallinity, high molecular weight, and corrosion resistance, embedded with copper nanoparticles in a homogenous dispersion, prepared using compatibilizers through the double melt mixing or dissolution method, which may also be able to form copper (II) oxide on its surface. Moreover, the best cleaning agent for this type of antimicrobial surface is an enzymatic cleaner, as it would not react with the polymer surface.

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