Reviewed research papers discussing the antimicrobial properties of copper-based metals

Here is a library of published papers and conference posters covering the laboratory and clinical studies conducted on the antimicrobial characteristics of solid copper and copper alloys over the last 20 years. Some papers are accessible here as pdfs, others have links to entries in various scientific libraries where full papers can be accessed via a subscription or for a cost.
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http://www.antimicrobialcopper.org/uk/scientific-references

Potential of copper alloys to kill bacteria and reduce hospital infection rates

Michels and Michels, Internal Medicine Review, March 2017

A large body of peer-reviewed literature has demonstrated in laboratory testing that placing bacteria in a highly concentrated bacterial inoculum onto copper alloy surfaces results in their rapid death. A smaller but convincing number of studies indicate that bacteria die on the surfaces of hospital room components made from copper alloys. Will the ability of copper alloys to kill bacteria translate into an ability to reduce the rate of hospital-acquired infections (HAIs)? This review addresses this question. In particular, the results of a clinical trial in which HAI rates are significantly reduced after introducing copper alloys components into Intensive Care Units of three hospitals will be presented. The findings suggest that copper alloys enhance hospital hygiene protocols because they act passively 24/7/365 requiring neither training nor human intervention to kill bacteria and reduce hospital-acquired infections.

Antimicrobial copper alloys decreased bacteria on stethoscope surfaces

Michael G. Schmidt et al. American Journal of Infection Control. 2017.

Background: Stethoscopes may serve as vehicles for transmission of bacteria among patients. The aim of this study was to assess the efficacy of antimicrobial copper surfaces to reduce the bacterial concentration associated with stethoscope surfaces.

Methods: A structured prospective trial involving 21 health care providers was conducted at a pediatric emergency division (ED) (n = 14) and an adult medical intensive care unit located in tertiary care facilities (n = 7). Four surfaces common to a stethoscope and a facsimile instrument fabricated from U.S. Environmental Protection Agency–registered antimicrobial copper alloys (AMCus) were assessed for total aerobic colony counts (ACCs), methicillin-resistant Staphylococcus aureus, gram-negative bacteria, and vancomycin-resistant enterococci for 90 days.

Results: The mean ACCs collectively recovered from all stethoscope surfaces fabricated from the AMCus were found to carry significantly lower concentrations of bacteria (pediatric ED, 11.7 vs 127.1 colony forming units [CFU]/cm2, P < .00001) than their control equivalents. This observation was independent of health care provider or infection control practices. Absence of recovery of bacteria from the AMCu surfaces (66.3%) was significantly higher (P < .00001) than the control surfaces (22.4%). The urethane rim common to the stethoscopes was the most heavily burdened surface; mean concentrations exceeded the health care–associated infection acquisition concentration (5 CFU/cm2) by at least 25×, supporting that the stethoscope warrants consideration in plans mitigating microbial cross-transmission during patient care.

Conclusions: Stethoscope surfaces fabricated with AMCus were consistently found to harbor fewer bacteria.

Copper alloy surfaces sustain terminal cleaning levels in a rural hospital

Shannon M. Hinsa-Leasure, Queenster Nartey, Justin Vaverka, Michael G. Schmidt. American Journal of Infection Control, 28 September 2016

Objective: To assess the ability of copper alloy surfaces to mitigate the bacterial burden associated with commonly touched surfaces in conjunction with daily and terminal cleaning in rural hospital settings.

Design: A prospective intention-to-treat trial design was used to evaluate the effectiveness of cooper alloy surfaces and respective controls to augment infection control practices under pragmatic conditions.

Setting: Half of the patient rooms in the medical-surgical suite in a 49-bed rural hospital were outfitted with copper alloy materials. The control rooms maintained traditional plastic, metal, and porcelain surfaces.

Methods: The primary outcome was a comparison of the bacterial burden harbored by 20 surfaces and components associated with control and intervention areas for 12 months. Locations were swabbed regardless of the occupancy status of the patient room. Significance was assessed using nonparametric methods employing the Mann-Whitney U test with significance assessed at $P < .05$.

Results: Components fabricated using copper alloys were found to have significantly lower concentrations of bacteria, at or below levels prescribed, upon completion of terminal cleaning. Vacant rooms were found to harbor significant concentrations of bacteria, whereas those fabricated from copper alloys were found to be at or below those concentrations prescribed subsequent to terminal cleaning.

Conclusions: Copper alloys can significantly decrease the burden harbored on high-touch surfaces, and thus warrant inclusion in an integrated infection control strategy for rural hospitals.

Perspectives from the field in response to "It is time to revise our approach to registering antimicrobial agents for health care settings"

Michael G. Schmidt, Joseph J. John Jr., Katherine D. Freeman, Peter A. Sharpe, Adam A. Estelle, Harold T. Michels. American Journal of Infection Control, 9 August 2016

The recent commentary, "It is time to revise our approach to registering antimicrobial agents for health care settings" by Alvarez et al1 provides welcome recognition that antimicrobial touch surfaces, such as copper alloys, offer a promising method to augment our capacity to combat health care-associated infections (HAIs). We agree that replacing high-touch surfaces in hospitals and elsewhere with continuously active, antimicrobial copper alloys provides an important means of reducing microbial burden during intervals between routine and terminal environmental cleanings.

Copper alloys - The new 'old' weapon in the fight against infectious disease

Harold T. Michels, Corinne A. Michels, Current Trends in Microbiology, Vol. 10 2016

Exposure to dry copper alloy surfaces, such as brass, kills a wide spectrum of microorganisms including Gram-negative and Gram-positive bacteria and fungi, and permanently inactivates several types of viruses.

A large body of published evidence reports that greater than 99.9% killing occurred within a 2-hour period when the microorganism was exposed to the copper alloy samples at room temperature and typical indoor humidity levels. Included in these studies were disease-causing bacteria such as E. coli O157:H7 as well as hospital "super-bugs" such as Methicillin- Resistant Staphylococcus aureus (MRSA) and Vancomycin-Resistant Enterococci(VRE). The results of these laboratory-based tests are reviewed here.

The mechanism(s) of action of copper alloy surface killing is still under investigation and progress on this important area of research will be described. It is important to note that mutations that provide resistance to copper alloy surface exposure have not been reported. These results suggest that copper alloy surfaces could be a powerful tool against the transmission of infectious disease in public settings, most particularly hospitals.

In a clinical trial, summarized here, the amount of live bacteria found on components made of copper alloys was compared to that found on components made from standard materials and shown to be 83% lower. Most significantly, when infection rates were tracked in these hospital rooms with the copper components and compared to rooms containing the standard components, it was found that the infection rates were reduced by a statistically significant 58%.

Thus, the widespread deployment of copper alloy components to frequently touched surfaces, such as door knobs and hand rails, has the potential to significantly reduce the rate of transmission of infections in the clinical settings and public-use spaces such as schools and transit systems.

Antimicrobial Applications of Copper

Marin Vincent, Philippe Hartemann, Marc Engels-Deutsch. International Journal of Hygiene and Environmental Health. doi:10.1016/j.ijheh.2016.06.003

Copper has long been known to have antimicrobial activity and is used in drinking water treatment and transportation. It has been recognized by the American Environmental Protection Agency as the first metallic antimicrobial agent in 2008. With ongoing waterborne hospital-acquired infections and antibiotic resistance, research on copper as an antimicrobial agent is again very attractive.

Many studies have shown that the use of copper surface and copper particles could significantly reduce the environmental bioburden. This review highlights in its first part all the conditions described in the literature to enhance copper antimicrobial activity. Secondly, the different antimicrobial applications of copper in water treatment, hospital care units and public applications are presented. Finally, the future research needs on copper as an antimicrobial agent are discussed.

From Laboratory Research to a Clinical Trial: Copper Alloy Surfaces Kill Bacteria and Reduce Hospital-Acquired Infections

Michels, H.T. 2015. Health Environments Research & Design Journal. 1–16.

Bacteria die on copper alloy surfaces in both the laboratory and the hospital rooms. Infection rates were lowered in those hospital rooms containing copper components. Thus, based on the presented information, the placement of copper alloy components, in the built environment, may have the potential to reduce not only hospital-acquired infections but also patient treatment costs.

Destruction of the Capsid and Genome of GII.4 Human Norovirus Occurs During Exposure to Metal Alloys Containing Copper

C. S. Manuel, M. D. Moore and L.A. Jaykus, Applied and Environmental Microbiology, 15 May 2015

Human norovirus (HuNoV) represents a significant public health burden worldwide and can be environmentally transmitted. Copper surfaces have been shown to inactivate the cultivable surrogate murine norovirus, but no such data exist for HuNoV.

The purpose of this study was to characterize the destruction of GII.4 HuNoV and virus-like particles (VLPs) when exposed to copper alloy surfaces. Fecal suspensions positive for a GII.4 HuNoV outbreak strain or GII.4 virus-like particles (VLPs) were exposed to copper alloys or stainless steel for 0 to 240 min and recovered by elution. HuNoV genome integrity was assessed by RT-qPCR (without RNase treatment), and capsid integrity was assessed by RT-qPCR (with RNase treatment), transmission electron microscopy (TEM), SDS-PAGE/Western blot analysis, and a histo-blood group antigen (HBGA) binding assay.

Exposing fecal suspensions to pure copper for 60 min reduced GII.4 HuNoV RNA copy number by approximately 3 log 10 when analyzed by RT-qPCR without RNase treatment, and 4 log 10 when a prior RNase treatment was used.

The rate of reduction in HuNoV RNA copy number was approximately proportional to the percent copper in each alloy. Exposing GII.4 HuNoV VLPs to pure copper surfaces resulted in noticeable aggregation and destruction within 240 min, an 80% reduction in VP1 major capsid protein band intensity in 15 min, and near complete loss of HBGA receptor binding within 8 min. In all experiments, HuNoV remained stable on stainless steel.

These results suggest that copper surfaces destroy HuNoV, and may be useful in preventing environmental transmission of the virus in at-risk settings.

Antimicrobial Properties of Copper in Gram-Negative and Gram-Positive Bacteria

Meyer, T.J. 2015. International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering. Vol:9, No:3.

For centuries humans have used the antimicrobial properties of copper to their advantage. Yet, after all these years the underlying mechanisms of copper mediated cell death in various microbes remain unclear. We had explored the hypothesis that copper mediated increased levels of lipid peroxidation in the membrane fatty acids is responsible for increased killing in Escherichia coli.

In this study, we show that in both gram positive (Staphylococcus aureus) and gram negative (Pseudomonas aeruginosa) bacteria there is a strong correlation between copper mediated cell death and increased levels of lipid peroxidation.

Interestingly, the non-spore forming gram positive bacteria as well as gram negative bacteria show similar patterns of cell death, increased levels of lipid peroxidation, as well as genomic DNA degradation, however there is some difference in loss in membrane integrity upon exposure to copper alloy surface.

Understanding the Role of Facility Design in the Acquisition and Prevention of Healthcare-associated Infections

Health Environments and Research Design Journal, Vol 7, Supplement, 2013

This special issue focuses on healthcare-associated infections and is sponsored by the Agency for Healthcare Research and Quality (AHRQ), part of the US Department of Health and Human Services. The majority of articles are the result of a project sponsored by the AHRQ. The project was designed to assess the rigor of claims asserting that design interventions can decrease infection risk, and to identify design strategies grounded in evidence that appear to be effective in interrupting the transmission of HAIs. This project represents a multidisciplinary assessment of the current state of knowledge and identifies emerging trends in the field of infection prevention within the context of the built environment. Copper touch surfaces are mentioned in several articles (p31, p46 and p127).

Enhancing Patient Safety through Strategic Placement of Copper Surfaces

M G Schmidt, C D Salgado, K A Sepkowitz, J F John, H H Attaway, III, R J Cantey, L L Steed, A A Estelle, H T Michels. Presented at the IPS Scottish Branch Conference 29 May 2014.

Poster presented on 29 May 2014 at the IPS Scottish Branch Conference 2014 - 'Get to Grips with SICPs' at Thistle Hotel, Glasgow, Scotland.

Copper Surfaces Reduce the Rate of Healthcare-Acquired Infections in the Intensive Care Unit

Cassandra D Salgado, MD; Kent A Sepkowitz, MD; Joseph F John, MD; J Robert Cantey, MD; Hubert H Attaway, MS; Katherine D Freeman, DrPH; Peter A Sharpe, MBA; Harold T Michels, PhD; Michael G Schmidt, PhD. ICHE, Vol. Vol. 34, No. 5, 2013., Infection Control and Hospital Epidemiology , Vol. 34, No. 5, Special Topic Issue: The Role of the Environment in Infection Prevention (May 2013), pp. 479-486.

Objective: Healthcare-acquired infections (HAIs) cause substantial patient morbidity and mortality. Items in the environment harbour microorganisms that may contribute to HAIs. Reduction in surface bioburden may be an effective strategy to reduce HAIs. The inherent biocidal properties of copper surfaces offer a theoretical advantage to conventional cleaning, as the effect is continuous rather than episodic. We sought to determine whether placement of copper alloy-surfaced objects in an intensive care unit (ICU) reduced the risk of HAI.

Design: Intention-to-treat randomized control trial between 12 July 2010 and 14 June 2011.

Setting: The ICUs of 3 hospitals.

Patients: Patients presenting for admission to the ICU.

Methods: Patients were randomly placed in available rooms with or without copper alloy surfaces, and the rates of incident HAI and/or colonization with methicillin-resistant Staphylococcus aureus (MRSA) or vancomycin-resistant Enterococcus (VRE) in each type of room were compared.

Results: The rate of HAI and/or MRSA or VRE colonization in ICU rooms with copper alloy surfaces was significantly lower than that in standard ICU rooms (0.071 vs 0.123). For HAI only, Pp.020 the rate was reduced from 0.081 to 0.034 (Pp.013).

Conclusions: Patients cared for in ICU rooms with copper alloy surfaces had a significantly lower rate of incident HAI and/or colonization with MRSA or VRE than did patients treated in standard rooms. Additional studies are needed to determine the clinical effect of copper alloy surfaces in additional patient populations and settings.

Copper Continuously Limits the Concentration of Bacteria Resident on Bed Rails within the Intensive Care Unit

Michael G Schmidt, PhD; Hubert H Attaway III, MS; Sarah E Fairey, BS; Lisa L Steed, PhD; Harold T Michels, PhD; Cassandra D Salgado, MD, MS Infection Control and Hospital Epidemiology, Vol. 34, No. 5.

Cleaning is an effective way to lower the bacterial burden (BB) on surfaces and minimize the infection risk to patients. However, BB can quickly return. Copper, when used to surface hospital bed rails, was found to consistently limit surface BB before and after cleaning through its continuous antimicrobial activity.

Special Topic Issue: The Role of the Environment in Infection Prevention (May 2013), pp. 530-533.

Experimental Tests of Copper Components in Ventilation Systems for Microbial Control

Charles Feigley, Jamil Khan, Deborah Salzberg, James Hussey, Hubert Attaway, Lisa Steed, Michael Schmidt and Harold Michels, (2013), HVAC&R Research, 19:1, 53-62

Colonization of HVAC systems by microbes may lead to release of hazardous bio-aerosols containing allergens, irritants, odorants or infectious agents to outdoor air, possibly adversely affecting system performance. Unlike the many common materials used in HVAC systems, copper and copper alloys have ben shown in laboratory investigations to kill bacteria and fungi on contact after several hours. This study tested copper's antimicrobial properties in comparison with aluminum in full-scale, carefully controlled air-conditioning systems, four with copper heat exchanger facilities and four with aluminum assemblies, at identical airflow rates, temperatures, humidity, and input microbe levels. Fungal and bacterial loads on copper surfaces in heat exchangers were lower than on aluminum surfaces by factors of 3500 and more than 500, respectively, over a 4-month period. No statistically significant difference in the release of airborne microbes was detected between copper and aluminum heat exchangers. The moderate conditions employed in this study, while still within the range commonly found in HVAC systems, possibly prevented the high microbial loading on aluminum heat exchanger surfaces from translating into significant differences in airborne concentrations between copper and aluminum systems.

Sustained Reduction of Microbial Burden on Common Hospital Surfaces through Introduction of Copper

Michael G Schmidt, Hubert H Attaway, Peter A Sharpe, Joseph John Jr, Kent A Sepkowitz, Andrew Morgan, Sarah E Fairey, Susan Singh, Lisa L Steed, J Robert Cantey, Katherine D Freeman, Harold T Michels, Cassandra D Salgado J Clin Microbiol July 2012 vol 50

The contribution of environmental surface contamination with pathogenic organisms to the development of healthcare-associated infections (HAI) has not been well defined. The microbial burden (MB) associated with commonly touched surfaces in intensive care units (ICUs) was determined by sampling six objects in 16 rooms in ICUs in three hospitals over 43 months.

At month 23, copper-alloy surfaces, with inherent antimicrobial properties, were installed onto six monitored objects in 8 of 16 rooms, and the effect that this application had on the intrinsic MB present on the six objects was assessed. Census continued in rooms with and without copper for an additional 21 months.

In concert with routine infection control practices, the average MB found for the six objects assessed in the clinical environment during the pre-intervention phase was 28 times higher (6,985 CFU/100 cm2; n = 3,977 objects sampled) than levels proposed as benign immediately after terminal cleaning (<250 CFU/100 cm2).

During the intervention phase, the MB was found to be significantly lower for both the control and copper-surfaced objects. Copper was found to cause a significant (83%) reduction in the average MB found on the objects (465 CFU/100 cm2; n = 2714 objects) compared to the controls (2,674 CFU/100 cm2; n = 2,831 objects [P < 0.0001]).

The introduction of copper surfaces to objects formerly covered with plastic, wood, stainless steel, and other materials found in the patient care environment significantly reduced the overall MB on a continuous basis, thereby providing a potentially safer environment for hospital patients, health care workers (HCWs), and visitors.

Supplemental Materials and Methods:

Table S1 - Assessment of the intrinsic microbial burden found on commonly encountered objects before an intervention with antimicrobial copper

Table S2 - Determination of the intrinsic microbial burden associated with six high-touch objects with or without copper surfaces within three ICUs

Figure S1 - Distribution of the microbial burden in the built environment is subject to stochastic forces

Figure S2 - Copper surfaces attenuate the inherent variability of the MB recovered from high-touch objects in the ICU

J Clin Microbiol July 2012 vol. 50 no. 7 2217-2223. Published ahead of print 2 May 2012, doi: 10.1128/JCM.01032-12.

Characterization and Control of the Microbial Community Affiliated with Copper or Aluminum Heat Exchangers of HVAC Systems

Michael G Schmidt, Hubert H Attaway, Silva Terzieva, Anna Marshall, Lisa L Steed, Deborah Salzberg, Hameed A Hamoodi, Jamil A Khan, Charles E Feigley, Harold T Michels. Curr Microbiol, 2012 May 9.

Microbial growth in heating ventilation and air conditioning (HVAC) systems with the subsequent contamination of indoor air is of increasing concern. Microbes and the subsequent biofilms grow easily within heat exchangers. A comparative study where heat exchangers fabricated from antimicrobial copper were evaluated for their ability to limit microbial growth was conducted using a full-scale HVAC system under conditions of normal flow rates using single-pass outside air. Resident bacterial and fungal populations were quantitatively assessed by removing triplicate sets of coupons from each exchanger commencing the fourth week after their installation for the next 30 weeks.

The intrinsic biofilm associated with each coupon was extracted and characterized using selective and differential media. The predominant organisms isolated from aluminum exchangers were species of Methylobacterium of which at least three colony morphologies and 11 distinct PFGE patterns we found; of the few bacteria isolated from the copper exchangers, the majority were species of Bacillus. The concentrations and type of bacteria recovered from the control, aluminum, exchangers were found to be dependent on the type of plating media used and were 11,411-47,257 CFU cm-2 per coupon surface. The concentration of fungi was found to average 378 CFU cm-2. Significantly lower concentrations of bacteria, 3 CFU cm-2, and fungi, 1 CFU cm-2, were recovered from copper exchangers regardless of the plating media used. Commonly used aluminum heat exchangers developed stable, mixed, bacterial/fungal biofilms in excess of 47,000 organisms per cm2 within 4 weeks of operation, whereas the antimicrobial properties of metallic copper were able to limit the microbial load affiliated with the copper heat exchangers to levels 99.97 % lower during the same time period.

Evaluation of Antimicrobial Properties of Copper Surfaces in an Outpatient Infectious Disease Practice

Seema Rai, Bruce E Hirsch, Hubert H Attaway, Richard Nadan, S Fairey, J Hardy, G Miller, Donna Armellino, Wilton R Moran, Peter Sharpe, Adam Estelle, J H Michel, Harold T Michels and Michael G Schmidt

Study investigating the impact of copper surfaces on the bacterial burden found on high-touch surfaces of phlebotomy chairs in an outpatient infectious disease clinic. Quantitative cultures were obtained from phlebotomy chairs located in an outpatient infectious diseases practice. Results from control (wood/composite) chairs and the copperized therapy chairs were compared. A total of 437 patients used the chairs during the 15-week study period.

Antimicrobial metallic copper surfaces kill Staphylococcus haemolyticus via membrane damage

Christophe Espírito Santo, Davide Quaranta, Gregor Grass. MicrobiologyOpen, Volume 1, Issue 1, pages 46–52, March 2012, DOI: 10.1002/mbo3.2

Molecular knowledge of the mode-of-action exerted by metallic Cu on microbes is certainly not strictly necessary for widespread application of antimicrobial surfaces in hygiene-sensitive areas. Currently, it is agreed-upon that genomic material will eventually degrade on metallic Cu (Weaver et al. 2011; Warnes and Keevil 2010; Espirito Santo and Grass, unpublished observations) but it is controversial if this process is causative for or subsequent to cell death (Weaver et al. 2010; Espirito Santo et al. 2011). We propose that current data favor the model that membranes are damaged first, causing lethality, followed by protein oxidation (Nandakumar et al. 2011) and DNA-degradation. In depth understanding of the sensitive cellular targets of Cu toxicity and the order of events leading to death, however, can be expected to provide new opportunities for improving the efficacy of Cu surfaces against microbes.

Antimicrobial activity of different copper alloy surfaces against copper resistant and sensitive Salmonella enterica

Libin Zhu, Jutta Elguindi, Christopher Rensing, Sadhana Ravishankar, Article in Food Microbiology 30 (2012) 303-310. Copyright 2011 Elsevier Ltd

Copper has shown antibacterial effects against foodborne pathogens. The objective of this study was to evaluate the antibacterial activity of copper surfaces on copper resistant and sensitive strains of Salmonella enterica. Six different copper alloy coupons (60-99.9% copper) were tested along with stainless steel as the control. The coupons were surface inoculated with either S. Enteritidis or one of the 3 copper resistant strains, S. Typhimurium S9, S19 and S20; stored under various incubation conditions at room temperature; and sampled at various times up to 2 h. The results showed that under dry incubation conditions, Salmonella only survived 10-15 min on high copper content alloys. Salmonella on low copper content alloys showed 3-4 log reductions. Under moist incubation conditions, no survivors were detected after 30 min-2 h on high copper content alloys, while the cell counts decreased 2-4 logs on low copper content coupons. Although the copper resistant strains survived better than S. Enteritidis, they were either completely inactivated or survival was decreased. Copper coupons showed better antimicrobial efficacy in the absence of organic compounds. These results clearly show the antibacterial effects of copper and its potential as an alternative to stainless steel for selected food contact surfaces.

Control and Mitigation of Healthcare-Acquired Infections

Peter A Sharpe, MBA, EDAC, and Michael G Schmidt, MA, PhD. Control and mitigation of healthcare-acquired infections: Designing clinical trials to evaluate new materials and technologies. Health Environments Research & Design Journal, 5(1), 94-115. 2011.

Hospitals clean environmental surfaces to lower microbial contamination and reduce the likelihood of transmitting infections. Despite current cleaning and hand hygiene protocols, hospital acquired infections (HAIs) continue to result in a significant loss of life and cost the U.S. healthcare system an estimated $45 billion annually. Stainless steel and chrome are often selected for hospital touch surfaces for their "clean appearance," comparatively smooth finish, resistance to standard cleaners, and relative effectiveness for removing visible dirt during normal cleaning. Designers use wood surfaces for aesthetics; plastic surfaces have become increasingly endemic for their relative lower initial cost; and "antimicrobial agents" are being incorporated into a variety of surface finishes. This paper concentrates on environmental surface materials with a history of bactericidal control of infectious agents and focuses on the methods necessary to validate their effectiveness in healthcare situations. Research shows copper-based metals to have innate abilities to kill bacteria in laboratory settings, but their effectiveness in patient care environments has not been adequately investigated. This article presents a research methodology to expand the evidence base from the laboratory to the built environment. For such research to have a meaningful impact on the design/specifying community, it should assess typical levels of environmental pathogens (i.e., surface "cleanliness") as measured by microbial burden (MB); evaluate the extent to which an intervention with copper-based materials in a randomized clinical trial affects the level of contamination; and correlate how the levels of MB affect the incidence of infections acquired during hospital stays.

Risk Mitigation of Hospital Acquired Infections Through the Use of Antimicrobial Copper Surfaces

W R Moran, H H Attaway, M G Schmidt, J F John, C D Salgado, K A Sepkowitz, R J Cantey, L L Steed, H T Michels. Poster presented at the American Hospital Association and Health Forum Leadership Summit 2011, July 17-19, 2011, San Diego, CA.

Each year hospital--- acquired infections (HAI) result in a substantial loss of life and an additional cost to the US healthcare system of $45 billion dollars. Evidence is presented illustrating how risk mitigation of the environmental burden resulted in a concomitant mitigation of the HAI rates for patients treated in rooms with antimicrobial copper touch surfaces. A discussion of the complexities and costs associated with effectively applying antimicrobial copper touch surfaces within the built environment will facilitate an understanding of the need for a design that makes use of emerging infection control solutions to fight HAIs in a pragmatic and aesthetically satisfying way.

The potential for the application of metallic copper surfaces as a method for preventing surface and airborne microbial contamination in military healthcare facilities, food handling operations, and other occupational settings

Anton Shufutinsky, Harold Michels, Wilton Moran, Adam Estelle, James Michel, Chris Dreska, Dennis Simon. Poster presented at 2011 US Armed Forces Public Health Conference.

Explains the potential application of Antimicrobial Copper surfaces as a method for preventing surface and airborne microbial contamination in military healthcare facilities, food handling operations, and other occupational settings.

Bacterial Killing by Dry Metallic Copper Surfaces

C Espírito Santo, E W Lam, C G Elowsky, D Quaranta, D W Domaille, C J Chang, and G Grass, 2011. Bacterial killing by dry metallic copper surfaces. Appl. Environ. Microbiol. 77: 794-802

Metallic copper surfaces kill microbes on contact, decimating their populations, according to a paper in the February 2011 issue of the journal Applied and Environmental Microbiology. They do so literally in minutes, by causing massive membrane damage after about a minute's exposure, says the study's corresponding author, Gregor Grass of the University of Nebraska, Lincoln. This is the first study to demonstrate this mechanism of bacteriocide.

"When microbes were exposed to copper surfaces, we observed contact killing to take place at the rate of tens to hundreds of millions of bacterial cells within minutes," says Grass. "This means that usually no live microorganisms can be recovered from copper surfaces after exposure."

Thus, such surfaces could provide a critical passive defense against pathogens in hospitals, where hospital-acquired infections are becoming increasingly common and costly, killing 50,000-100,000 Americans annually, and costing more than $8 billion, according to one estimate. Still, Grass cautions that "metallic copper surfaces will never be able to replace other hygiene-improving methods already in effect," although they "will certainly decrease the costs associated with hospital-acquired infections and curb human disease as well as save lives." However, he expects this strategy to be inexpensive, because "the effect does not wear off."

Critically, the researchers provide strong evidence that genotoxicity through mutations and DNA lesions is not a cause of dry copper's antimicrobial properties. This is important, because mutations can cause cancer in animals and humans, and the lack of such mutations in bacteria from copper means that copper does not endanger humans.

The relevant experiment was particularly interesting. The bacterium, Deinococcus radiodurans, is unusually resistant to radiation damage, as its DNA repair mechanisms are especially robust. The hypothesis: if metallic copper kills by causing DNA damage, D. radiodurans should be immune to copper. It is not.

It is important to note that only dry copper surfaces are amazingly lethal to bacteria. The difference between dry and wet surfaces, such as copper pipes, is that only dry surfaces are inhospitable environments for bacterial growth. Bacteria can easily grow and reproduce in wet environments, and in so doing, they can develop resistance to copper. Resistance has not been observed to develop on dry copper surfaces.

Metallic Copper as an Antimicrobial Surface

Gregor Grass, Christopher Rensing and Marc Solioz, Appl. Environ. Microbiol. March 2011, pp 1541-1547. Vol 77, No 5. doi: 10.1128/AEM.02766-10,

Bacteria, yeast, and viruses are rapidly killed on metallic copper surfaces and the term 'contact-killing' has been coined for this process. While the phenomenon has already been known in ancient times, it is currently receiving renewed attention. This is due to the potential use of copper as an antibacterial material in health care settings. Contact-killing was observed to take place at the rate of seven to eight logs per hour or even minutes and no live microorganisms were generally recovered from copper surfaces after prolonged incubation. The antimicrobial activity of copper and copper alloys is now well established and copper has recently been registered at the U.S. Environmental Protection Agency as the first solid antimicrobial material. In several clinical studies, copper has been evaluated for use on touch-surfaces such as door handles, bathroom fixtures, or bed rails, in attempts to curb nosocomial infections. In connection to these new applications of copper, it becomes of importance to understand the mechanism of contact-killing as it may bear on central issues, such as the possibility of the emergence and spread of resistant organisms, cleaning procedures, and questions of material and object engineering. Recent work has shed light on mechanistic aspects of contact-killing. These findings will be reviewed here and juxtaposed to the toxicity mechanisms of ionic copper. The merit of copper as a hygienic material in hospital and related settings will also be discussed.

Mechanisms of Contact-Mediated Killing of Yeast Cells on Dry Metallic Copper Surfaces

Davide Quaranta, Travis Krans, Christophe Espírito Santo, Christian G Elowsky, Dylan W Domaille, Christopher J Chang, Gregor Grass, Applied & Environmental Microbiology. Jan. 2011, p.416–426 Vol. 77, No. 2 0099-2240/11/$12.00 doi:10.1128/AEM.01704-10 ASM

Surfaces made of copper or its alloys have strong antimicrobial properties against a wide variety of microorganisms. However, the molecular mode of action responsible for the antimicrobial efficacy of metallic copper is not known. Here, we show that dry copper surfaces inactivate Candida albicans and Saccharomyces cerevisiae within minutes in a process called contact-mediated killing.

Copper Surfaces Reduce the Microbial Burden in Out-Patient Infectious Disease Practice

B E Hirsch, H Attaway, R Nadan, S Fairey, J Hardy, G Miller, S Rai, D Armellino, M Schilling, W Moran, P Sharpe, A Estelle, J H Michel, H T Michels, M G Schmidt, Interscience Conference on Antimicrobial Agents and Chemotherapy, Boston, MA, 2010

Copper alloy surfaces are known to kill bacteria and decrease the environmental microbial bio-burden (MB) in ICUs. Out-patients share risk factors including co-morbidities, antibiotic exposure plus recent hospitalization. The transient and high volume of potentially infectious and vulnerable subjects renders the out-patient clinic a significant locus of transmission that is often overlooked. This study shows the benefit of copper surfaces for their ability to reduce the MB in an infectious disease out-patient practice. These findings support the clinical trial findings from Selly Oak, Calama and MUSC and, in addition, show a halo effect - reduced contamination in the vicinity of the copper surfaces. The calculated ratio of patients to the median burden enabled the conclusion to be drawn that use of the chair with the copper arm tops resulted in a 17-fold lower risk of exposure to environmental microbes than when patients used the standard chair.

A Pilot Study to Determine the Effectiveness of Copper in Reducing the Microbial Burden (MB) of Objects in Rooms of Intensive Care Unit (ICU) Patients

C D Salgado, A Morgan, K A Sepkowitz et al. Poster 183, 5th Decennial International Conference on Healthcare-Associated Infections, Atlanta, March 29, 2010

The first results from the US Department of Defense-funded 3-centre copper clinical trial show a significant reduction in bioburden on copper items compared to controls. Neither VRE nor MRSA were found on any copper items.

Effects of Temperature and Humidity on the Efficacy of Methicillin-resistant Staphylococcus Aureus Challenged Antimicrobial Materials Containing Silver and Copper

H T Michels, J O Noyce, and C W Keevil, Letters in Applied Microbiology, 49 (2009) 191-195

Demonstrates that commercially available silver ion-containing coatings marketed as antimicrobial do not exhibit any meaningful reduction of MRSA under typical indoor conditions. Copper alloys exhibited antimicrobial efficacy under all tested conditions.

Microbial Burden (MB) of Objects (obs) in ICU Rooms (rms)

C D Salgado, K A Sepkowitz, T Plaskett, J F John, J R Cantey, H H Attaway, L L Steed, H T Michels, M G Schmidt. October 2008.

This study sought to determine the microbial burden (MB) on frequently touched inanimate objects in the ICU rooms of patients at three different US hospitals. The findings showed that Staphylococci were the predominant organism isolated within this MB.

Objects found in ICU rooms can serve as a reservoir for the spread of bacteria, particularly staphylococci, to patients, healthcare workers, and visitors. Objects in close proximity to patients pose the greatest risk, particularly bed rails.

Patient acquisition of organisms that were recovered from ICU rooms may lead to healthcare-acquired infections resulting in substantial morbidity and mortality. Future studies should focus on strategies to reduce high level bacterial contamination of common objects in patient rooms and potential spread of these bacteria in order to potentially reduce healthcare-acquired infections.

Antimicrobial Properties of Copper Alloy Surfaces, with a Focus on Hospital-Acquired Infections

H Michels, W Moran and J Michel, International Journal of Metalcasting, Summer 2008, pp 47-56

Discusses the antimicrobial properties of copper alloys and their potential to reduce the number of certain bacteria on frequently touched surfaces. Efficacy data address other materials and the effects of tarnishing, bacteria concentration and repeated contamination. EPA testing, results and registration are highlighted.

Antimicrobial regulatory efficacy testing of solid copper alloy surfaces in the USA

H T Michels and D G Anderson, pp 185-190, Metal Ions in Biology and Medicine: Vol 10, Eds Ph Collery, I Maymard, T Theophanides, L Khassanova, T Collery. John Libbey Eurotext, Paris © 2008

Discusses potential impact of antimicrobial copper alloys on amount of certain bacteria on frequently touched surfaces in healthcare settings. Describes the steps required to make public health claims and summarizes EPA test protocols and results.

The Antimicrobial Properties of Copper Alloys and their Potential Applications

H T Michels, D G Anderson, J O Noyce, S A Wilks and C W Keevil, Proceedings of the Sixth International Copper-Cobre Conference, pp 121-133, Vol I, August 2007

Describes potential healthcare applications and barriers for antimicrobial copper alloys. Authors review efficacy data against various organisms and EPA testing.

Antimicrobial Characteristics of Copper

H T Michels, ASTM Standardization News, October 2006.

Article provides an overview on the antimicrobial characteristic of copper. Describes the research performed to date and the potential applications of antimicrobial copper products. Includes a letter from the editor which highlights the article.

Copper Alloys for Human Infectious Disease Control

H T Michels, J P Noyce, S A Wilks and C W Keevil. Copper for the 21st Century, Materials Science & Technology 2005 (MS&T'05) Conference, Pittsburgh, PA, September 25-28, 2005, ASM, ACerS, AIST, AWS, TMS, ISSN: 1546-2498

Illustrates the ability of copper alloys to kill several food borne pathogens known to cause infection. Also demonstrates efficacy against Methicillin-resistant Staphylococcus aureus which is largely responsible for hospital acquired infections. Stainless steel, the control, had no effect on any of the pathogens. Results suggest copper alloys may reduce the levels of infectious pathogens on surfaces in contact with food and touched by humans.

The Effects of Copper Alloy Surfaces on the Viability of Bacterium, E. coli 0157:H7

H T Michels, S A Wilks and C W Keevil. The Second Global Congress Dedicated to Hygienic Coatings & Surfaces, Orlando, Florida, USA, 26-28 January, 2004, Paper 16, Published by Paint Research Association, Middlesex, UK, ISBN 0-9543164-5-2, 2004.

Tests the viability of E. coli O157:H7 on a variety of copper alloy surfaces. All tested copper alloys rendered the bacteria non-viable after several hours. E. coli O157:H7 has been responsible for a number of food recalls and can survive on stainless steel for days. Results suggest copper alloys will be useful beyond food processing applications.

The Antimicrobial effects of copper alloy surfaces on the bacterium, E. coli 0157:H7

H T Michels, S A Wilks and C W Keevil, Proceedings of Copper 2003 - Cobre 2003, The 5th International Conference, November 30-December 2, 2003, Santiago, Chile, Vol. 1 - Plenary Lectures, Economics and Applications of Copper, pp. 439-450

Investigates the viability of E. coli O157:H7 on 25 copper alloy surfaces at 20C and 4C (refrigeration temperature). Bacteria reduction occurred with all alloys and was faster at the higher temperature and on alloys containing higher levels of copper. Further research is recommended to determine copper's effect on molds and other organisms that cause respiratory infections.

A Publication of The Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, Canada, 2003.

Doorknobs: a source of nosocomial infection?

P J Kuhn, Diagnostic Medicine, 1983.

Discusses the unique bactericidal properties of copper and brass compared to stainless steel and aluminum against various organisms. Results suggest that hospitals should utilize brass (copper alloy) hardware to minimize bacterial growth on these surfaces.