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Effect of Copper-coated Surfaces on the Bacterial Burden in the Intensive Care Unit

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Abstract

Background: Pathogen-contaminated surfaces are known to transmit Healthcare-Associated Infections in hospitals and other healthcare facilities. Existing hospital-cleaning procedures alone are not enough to prevent the growth of microorganisms over time. Since copper alloy has inherent and continuous antibacterial properties, copper surfaces offer a solution to complement these procedures.
Objectives: This study aimed to assess the antibacterial effects of copper-coated surfaces on the bacterial burden in the intensive care unit (ICU).
Methods: This clinical controlled trial was conducted in a general ICU. The bacterial burden was measured on five surfaces that were coated with a copper alloy foil (purity 99.94%, 100-micron thickness) and five similar surfaces without the copper coating (n=60 each). The total bacterial burden and the colonization rate of Staphylococci, vancomycin-resistant enterococci, and gram-negative bacilli were measured on different surfaces. The collected data were analyzed using Chi-square or Fisher's exact, Shapiro-Wilk, Mann-Whitney, and Kruskal-Wallis tests.
Results: The cumulative bacterial burden was lower on copper-coated surfaces than on control surfaces. The copper-coated surfaces were found to have a significantly (95.96%) lower mean bacterial burden (145.20 colony-forming units [CFU]/100 cm2, n=60 surfaces) than the control surfaces (3,598.74 CFU/100 cm2, n=60 surfaces; P<0.001).
Conclusion: The results of this study showed that placing a copper coating on the surface of five common, highly touched objects in ICU rooms reduced the bacterial burden by 96%, as compared with control surfaces.

Keywords: Chain of infection, Copper alloy, Healthcare-associated infections, Intensive care unit, Microbacterium

1. Background

Healthcare-associated infections (HAIs) are infections that result from staying in hospitals or other healthcare centers to receive healthcare services. These infections tend to appear after 2 days of hospitalization or within a month after discharge (1) and they are known to have a particularly high burden in developing countries (2). In a study conducted in several Iranian hospitals, the overall rate of HAIs was reported to be 96.61 per 1,000 patients in the intensive care unit (ICU) (3). The results of studies have shown that patients with HAIs, compared to none infected patients, tend to have a longer length of stay (21.6 vs. 4.9 days), higher readmission rates within 30 days (29.8% vs. 6.2%), and greater mortality (9.4% vs. 1.8%) (4).

It has been estimated that existing evidence-based HAIs prevention strategies can hinder up to 65-70% of catheter-associated bloodstream and urinary tract infection cases and 55% of ventilator-associated pneumonia and surgical site infection cases. Catheter-associated bloodstream infections are known to have higher mortality rates and economic burdens than other infections of this kind (5).

The considerable morbidity rate and economic burden of HAIs highlight the need for better HAIs prevention and infection-control practices (2). It has been estimated that roughly 20-40% of all HAIs originate from healthcare workers touching surfaces and objects around patients with contaminated hands (6), which is an unavoidable part of everyday life. As a result, touching pathogen-contaminated surfaces may become a major mechanism of disease transmission. Some researchers have observed a logistic increase in the number of pathogen-contaminated surfaces under certain conditions, with potential association with the infection transmission rate. After touching contaminated surfaces and objects, people can carry pathogens quickly to great distances. Once pathogens enter a small room, most of the frequently touched surfaces can be contaminated within 2-3 h, and almost all of the touchable surfaces can be contaminated within 5-6 h (7).

An obvious HAIs prevention strategy is to prevent pathogen transmission through high-touch surfaces, which can be contaminated by a wide variety of microorganisms, including gram-positive and gram-negative bacteria, viruses, yeasts, and parasites. This goal can be achieved by ensuring that these surfaces are adequately cleaned and disinfected. The existing manual and automated surface cleaning and disinfection techniques have shown varying degrees of effectiveness in achieving this goal (8). However, multiple reports are suggesting that these techniques alone may not be enough to inhibit pathogen growth in hospital settings (9). While several novel antibacterial surface coatings have been introduced in recent decades, they have remained largely unused because of concerns over their durability, resistance, and potential toxicity (8). These coatings include five groups of copper alloys, which have been approved by the United States Environmental Protection Agency as antibacterial materials with public health benefits (10).

There is clinical evidence supporting the claim that copper alloy can reduce the microbial burden of surfaces in clinical settings. In one study, hospital rooms, where frequently touched objects were made of copper alloys, had a considerably lower bacterial burden and infection rates than ordinary rooms (11). The antibacterial effect of copper alloys is primarily related to metallic Cu, which is not genotoxic. In other words, this metal kills pathogens by damaging their cell membranes rather than damaging their DNA (12). The findings of some clinical studies show as much as an 83% reduction in bacterial burden and a 58% decrease in infection rate after using copper alloys on high-touch surfaces in healthcare environments (11, 13). Moreover, some researchers have reported a significant reduction in the microbial burden of hospital rooms with copper alloy surfaces without reporting on the clinical efficacy of this measure (11, 13).

2. Objectives

This paper presented the results of a clinical trial conducted to determine the effect of using five copper-coated surfaces in ICU rooms on the bacterial burden.

3. Methods

3.1. Study design

This study was conducted based on a controlled clinical trial design. Before initiating the study, the protocol was registered at the Iranian Registry of Clinical Trials with the registration number IRCT20180629040279N2. The study was carried out in the general ICU of Ayatollah Kashani Hospital, a 264-bed tertiary public hospital in Isfahan, Iran, offering specialty services in orthopedics, neurology, and ear, nose, and throat from January 20, 2021, to February 20, 2021. This ICU has one 4-bed room and one 3-bed room with almost 80 admissions per month.

For better inter-group comparisons, one bed in the 4-bed room was excluded from the study. The two rooms, now each having 3 beds, were then randomly assigned to an intervention group (copper beds) and a control group (control beds) by coin tossing. Since the patients' length of stay and date of discharge were not predictable, a non-random design was used to allocate the patients into the intervention and control groups.

The inclusion criteria were all females and males who were 18 years old and above and were admitted to ICU for any reason. On the other hand, pregnant women and patients with Wilson's disease were excluded from the study.

3.2. Intervention

A total of 5 surfaces in half of the beds (n=3) were coated with copper foil. These surfaces were more common touchable surfaces, which surround the patient bed, including the bed footboard, the intravenous pole (IV pole), the upper surface of the suction machine, the over-bed table, and the bedside locker (14) (Figure 1).

Figure 1. Copper-coated surfaces: (1) Over-bed table, (2) Bedside locker, (3) Intravenous pole, (4) Upper surface of the suction machine, and (5) Bed footboard

Copper foils were glued to the surfaces smoothly and evenly without creating sharp edges. These foils were manufactured by Shahid Bahonar Copper Factory in Kerman, Iran, with a thickness of 100 microns. To ensure the purity of copper foils, their copper content was measured in a laboratory, finding them to be 99.94% pure. A warning sign was installed above each copper bed to warn personnel about the risk of electric shock.

In the control group, samples were collected from five surfaces, including the bed footboard, the IV pole, the upper surface of the suction machine, the over-bed table, and the bedside locker, which were made of conventional materials, namely stainless steel, aluminum, and polyvinyl chloride (PVC).

Handwashing rules and cleaning routines remained the same throughout the study period. In order to control the interfering factors, all samples were collected by one person at a certain time, which was when the probability of bacterial growth was higher due to the longer interval in the usual disinfection of surfaces; therefore, they were collected at the end of the night shift. Samples were also blinded for the laboratory technician who examined the samples.

3.3. Outcome measures

The primary outcome was the total bacterial burden, expressed as viable colony-forming units (CFU) per 100 square centimeters (cm2), and the secondary outcomes were the colonization rates of Staphylococcus aureus, vancomycin-resistant enterococci (VRE), and gram-negative bacilli on different surfaces. In addition, any possible side effects of contact with copper in the patients and staff were assessed as a secondary outcome.

3.4. Environmental sampling

For both groups, samples from the 5 surfaces were collected at 6 am before the morning disinfection routine for 4 consecutive weeks. For sampling, a sterile sampling template (5×5 or 2.5×10 cm) was placed over the surface, and the exposed area was wiped horizontally and vertically by wet sterile swabs with uniform, vigorous pressure (15). The swabs were then placed back in the sterile tubes containing normal saline (1 ml). A total of 60 bacterial samples were obtained from each group and transferred to a microbiology laboratory for processing.

3.5. Bacterial tests

The surfaces were assessed for Aerobic Colony Count, expressed as viable CFU per 100 cm2, and the colonization rates of S. aureus, VRE, and gram-negative bacilli (e.g., Escherichia coli, Klebsiella pneumoniae, and Acinetobacter baumannii). For bacterial tests, the tubes containing swabs were first vortexed for 1 min. After a pilot test to determine the bacterial burden limits, appropriate dilutions were prepared. The sample was diluted by sheep blood agar, and 100 µl of the product was plated. To isolate pathogens from clinical samples, Mannitol Salt Agar was used for S. aureus, Bile Esculin Azide Agar for VRE, and MacConkey Agar for gram-negative bacilli. After 48 h incubation at 37°C, the appeared colonies were counted and the bacterial count was calculated by the following formula:

Number of colonies × 1/volume transferred to plate × 1/dilution factor = CFU/ml (16)

Finally, the resulting CFU/ml was quadrupled and converted into CFU/100 cm2.

3.6. Ethical considerations

Written informed consent was obtained from every patient or his/her legal guardian within 24 h of admission. The Ethics Committee of Islamic Azad University, Isfahan Branch (Khorasgan), Isfahan, Iran, approved the study protocol with the code KHUISF.REC.1399.210 IR.IAU.

3.7. Statistical analysis

The sample size was calculated at 15 per group based on the difference between average bacterial colonization rates on copper-coated and control surfaces. The two-way analysis was conducted at a significant level of 5% (α=0.05) with an analysis power of 80% (2/B=0) to detect a difference of at least 5% greater than the standard deviation (δ=1.05 σ).

A bacterial burden of less than 250 aerobic CFU per 100 cm2 of surface area can be considered low-risk (17). Therefore, only the surfaces with a bacterial burden of more than 250 CFU/100 cm2 were analyzed with Chi-square or Fisher's exact test. The mean bacterial burden of each bed was calculated, and the bacterial burden of each bed surface was determined as the sum of the bacterial burden of the five surfaces within that room (15). Since the Shapiro-Wilk test could not confirm the normality of data distribution, the analyses were performed with nonparametric methods. Mann-Whitney analysis was employed to compare the bacterial burden of similar copper-coated and control surfaces, and Kruskal-Wallis analysis was used to compare the bacterial burden of different surfaces. Data were reported in terms of mean, standard deviation, median, and interquartile range. The analysis was performed at a significance level of 5%.

4. Results

A total of 28 patients hospitalized in beds with copper-coated surfaces and control surfaces were included in the study. The mean age of the patients was obtained at 43.81 years and almost half of them were connected to ventilator machines. The patients hospitalized in beds with control surfaces had a longer length of stay. There was no significant difference between the two groups of patients in terms of demographic and clinical characteristics (Table 1).

Table 1. Demographic and clinical characteristics of patients

Characteristics		Copper-coated surfaces n=13	Standard surfaces n=8	Total	P-value
(mean±SD) Age		42.77±19.35	45.50±18.37	43.81±18.57	*0.860
Male		)%6 (46.20	)%5 (62.50	11 (52.38%)	**0.670
ICU length of stay (mean days±SD)		4.75±4.68	8.86±11.94	6.67±8.75	*0.9.07
Comorbidity	Diabetes	2 (15.40%)	2 (25%)	4 (19.04%)	**0.618
	Cancer	4 (30.80%)	1 (12.50%)	5 (23.80%)	**0.606
	Renal failure	0 (0%)	1 (12.50%)	1 (4.76%)	**0.381
	Heart diseases	1 (7.70%)	0 (0%)	1 (4.76%)	**1.00
Endotracheal tube		6 (46.20%)	4 (50%)	10 (47.61%)	**1.00
Tracheostomy		1 (7.70%)	1 (12.50%)	2 (9.52%)	**1.00
Connected to ventilator		6 (46.20%)	5 (62.50%)	11 (52.38%)	**0.659
GCS (mean±SD)		13±3.24	10.38±4.50	12±3.89	

ICU: Intensive care unit; GCS: Glasgow Coma Scale
*Mann-Whitney test; **Fisher's Exact test

The results showed a lower cumulative bacterial burden in the beds with copper-coated surfaces than in those with standard surfaces.

The copper-coated surfaces were found to have a significantly (95.96%) lower mean bacterial burden (145.20 CFU/100 cm2, n=60 surfaces) than the control surfaces (3,598.74 CFU/100 cm2, n=60 surfaces; P<0.001). The impact of copper-coating was detected on the colonization rate of VRE in three out of five surfaces, namely the IV pole (P=0.017), the upper surface of the suction machine (P=0.001), and on the over-bed table (P=0.026). It was revealed that the mean colonization rate of S. aureus on the copper-coated IV pole (P=0.004) and over-bed table (P=0.017) surfaces were significantly lower than those in the control surfaces.

As the results showed, there was also a statistically significant difference (P<0.001) between the mean bacterial burden of gram-negative bacilli (e.g., E. coli, K. pneumoniae, and A. baumannii) on the copper-coated and that on the control surfaces (137.34 versus 3,358 CFU/100 cm2) (Table 2).

The results of Fisher's exact test showed that a significantly greater number of control surfaces had a mean bacterial burden exceeding 250 CFU/100 cm2 than copper-coated surfaces (P<0.001) (Figure 2).

Pathogens accounting for the highest mean bacterial burden on the surfaces were gram-negative bacilli, S. aureus, and VRE, in descending order. On the copper-coated surfaces, however, the bacterial burden of VRE was higher than that of S. aureus. The most contaminated surfaces of the control group were the bedside locker, the over-bed table, the bed footboard, the upper surface of the suction machine,

Table 2. Bacterial burden (CFU/100 cm^2) on copper-coated surfaces versus control surfaces

Bacteria type	Surface types	Copper-coated surfaces (n=60)		Standard surfaces (n=60)		Percentage reduction of bacterial burden	*P-Value
		Mean±SD	Median (IQR)	Mean±SD	Median (IQR)		
Bacterial burden	Bed Footboard	113.30±74.80	120 (126.25)	3141.20±2010.80	2935 (3950)	96.39%	<0.001
	Bedside locker	92.30±69.50	97.50 (147.50)	4690.30±2059.50	4825 (2405)	98.03%	<0.001
	IV pole	144.20±120.90	115 (245)	3281.70±1973.60	2360 (2695)	95.60%	<0.001
	Suction machine	189±146	189 (272.50)	2638.80±1721	2150 (3095)	92.83%	<0.001
	Bed table	190.80±189.70	127.50 (348.75)	4241.70±2618	3601 (4732.50)	95.50%	<0.001
****P-Value**		0.494		0.154			
VRE	Footboard of the bed	0.80±2.90	0 (0)	13.30±31.10	0 (0)		0.241
	Bedside locker	5±17.30	0 (0)	2±3.70	0 (4.50)		0.176
	IV pole	0±0	0 (0)	16.70±25	0 (47.50)		0.017
	Suction machine	0±0	0 (0)	26.70±29.30	25 (47.50)		0.001
	Bed table	3.30±11.50	0 (0)	24.30±32.10	12 (57.50)		0.026
P-Value [b]		0.722		0.258			
Staphylococcus aureus	Footboard of the bed	1.70±5.80	0 (0)	6.70±17.20	0 (7.50)		0.153
	Bedside locker	0±0	0 (0)	26.70±62.90	0 (0)		0.074
	IV pole	2.50±6.20	0 (0)	25.80±28.10	15 (55)		0.004
	Suction machine	2.50±4.50	0 (7.50)	23.80±47.70	5 (20)		0.054
	Bed table	0±0	0 (0)	17.30±33.90	0.0 (25)		0.017
P-Value [b]		0.208		0.168			
Gram-negatives bacilli	Footboard of the bed	108.30±79	120 (138.7)	2885±1923.50	2750 (3987.50)		<0.001
	Bedside locker	79.80±58.500	80 (93.75)	4591.70±2038.50	4750 (2500)		<0.001
	IV pole	141.70±123.10	110 (245)	2912.50±2201.70	2200 (3737.50)		<0.001
	Suction machine	171.50±141.90	189 (255)	2458.30±1698.40	2000 (3000)		<0.001
	Bed table	185.40±187	127.50 (332.5)	3942.50±2540.80	3000 (3750)		<0.001
****P-Value**		0.547		0.059			

IV: Intravenous; IQR: Interquartile range; VRE: Vancomycin-resistant enterococci
*Mann-Whitney U test (one-tailed); **Kruskal Wallis test (two-tailed)

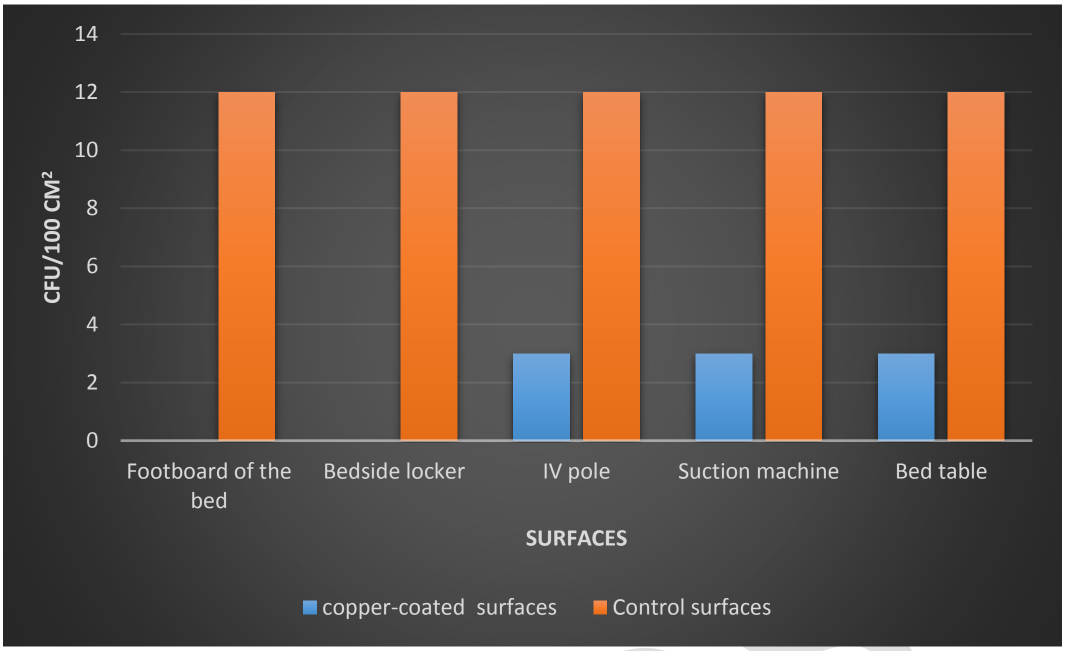

Figure 2. Frequency of surfaces with a bacterial burden more than 250 CFU/100 cm²

and the IV pole in descending order. Nevertheless, among the copper-coated surfaces, the most contaminated surfaces were the over-bed table, the upper surface of the suction machine, the IV pole, the bed footboard, and the bedside locker by decreasing order.

4.1. Adverse effects

A sheet reporting the possible side effects of contact with copper was prepared according to the review of studies and was completed daily for patients and staff working in the environment. Complications, included itching, redness, swelling, warmth, blisters, nasal ulcers, and any other possible suspected lesions. Neither patients nor staff showed any adverse effect of contact with copper during 4 weeks.

5. Discussion

The results of the study demonstrated that placing copper coatings on the surface of five common, highly touched objects in ICU rooms reduced the bacterial burden by 95.96%, compared to control surfaces, which were made of conventional materials, including stainless steel, aluminum, and PVC. Copper-coated surfaces provide a passive way of reducing bacterial burden without requiring the staff to take any action or follow any complex procedure or needing buy-ins from other providers. Furthermore, since the antibacterial effect of copper is a continuous property, it strongly mitigates the regrowth of pathogens. While it might be expensive to fit hospital rooms with copper-coated surfaces, some have estimated that considering its impact on controlling HAIs makes this measure a sound investment with a payback period of fewer than 2 months (11).

In this study, the copper components were found to be effective in controlling bacterial burden to roughly the same degree that they were reported to be in a pediatric trial (14). In addition, no adverse effect was found from the copper contact in patients or staff during 4 weeks. This result was consistent with other reports on the lack of adverse events following the exposure of human skin to metallic copper materials used for interventions (14). In another study, copper oxide was even embedded in fibers to make copper oxide-containing nonstick pads for wound dressing, and the resulting product caused no side effects, such as skin irritation or sensitization, to closed skin in rabbits (18).

While there are some concerns about bacteria developing resistance to copper exposure, the findings of pieces of research have shown that this is unlikely because copper's anti-bacterial effect has multiple mechanisms of action. Moreover, despite the wide use of copper in the United Kingdom, there has been no report of such bacterial resistance in this country (19). It should be noted that since the copper used in hospital equipment or furniture might become discolored after a while because of oxidation, hospital managers should apply policies to maintain its beauty and luster, such as periodic use of copper gloss solutions and the utilization of copper in combination with copper alloy with other metals.

Considering that in the current study, the surfaces were coated with 99.9% pure copper, it is noteworthy that different results might have been produced if the copper was less pure or combined with other metals, such as tin. Although bed frames are widely believed to be among the most contaminated parts of a hospital room, it was impossible to cover them with copper foil because of the presence of a control panel connected to a power supply; regarding this limitation, the generalizability of our results should be performed by cautious. It should be remembered that given the electrical conductivity of copper, using copper alloys in replace of other materials such as PVC, especially in bed frames or footboards, comes with a risk of electric shock. It may become more problematic when the bed is equipped with an electric control panel or when patients need to receive a direct current shock during cardiovascular resuscitation. Consequently, it is necessary to take some measures, such as installing warning signs, to inform the staff about the risk of electric shock.

There were several methodological challenges to conducting this research as a double-blinded randomized controlled trial. First, it was impossible to blind participants, staff, and researchers, as everyone could easily recognize the unique appearance of copper alloys. Second, randomization was difficult since the intervention failed to function at the individual level. Finally, in busy ICU rooms, it was not possible to randomly assign a patient to a particular bed. Despite the randomization concern, both groups looked comparable from the perspective of common clinical characteristics that are likely to introduce bias to findings. To the best of our knowledge, no study has calculated the cost-effectiveness of copper surfaces, it is recommended to perform further studies to assess the benefits of copper-surfaced equipment for healthcare settings.

6. Conclusion

The results of this study showed that placing a copper coating on the surface of five common, highly touched objects in ICU rooms reduced the bacterial burden by 96%, as compared with control surfaces.

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Footnotes

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Conflicts of Interest: None of the researchers was involved in copper-related industries or mines.

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