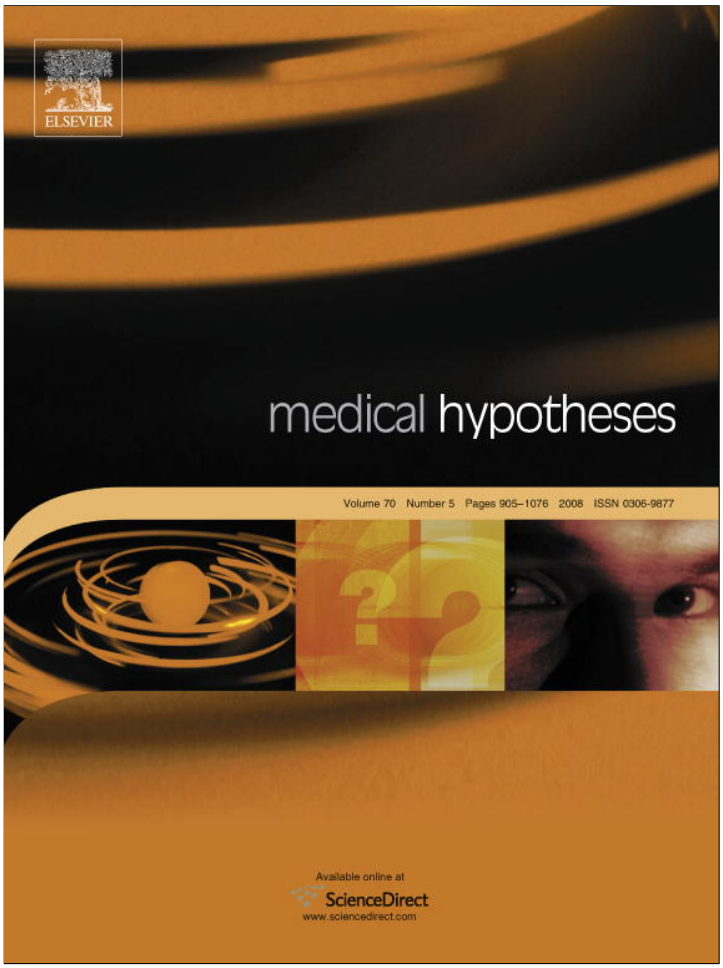

Medical Hypotheses (2008) **70,** 990–994

ELSEVIER

medical hypotheses

http://intl.elsevierhealth.com/journals/mehy

Biocidal textiles can help fight nosocomial infections

Gadi Borkow *, Jeffrey Gabbay

Cupron Inc., P.O. Box 10973, Greensboro, NC 27404, USA

Received 12 August 2007; accepted 14 August 2007

Summary The rates of nosocomial infections, especially by those caused by antibiotic resistant bacteria, are increasing alarmingly over the globe. Although more rigorous infection control measures are being implemented, it is clear that the current modalities to reduce nosocomial infections are not sufficient.

Textiles are an excellent substrate for bacterial growth under appropriate moisture and temperature conditions. Patients shed bacteria and contaminate their pyjamas and sheets. The temperature and humidity between the patients and the bed are appropriate conditions allowing for effective bacterial proliferation. Several studies have found that personnel in contact with contaminated textiles were the source of transmission of the micro-organisms to susceptible patients. Furthermore, it has been reported that bed making in hospitals releases large quantities of micro-organisms into the air, which contaminate the immediate and non-immediate surroundings. Contaminated textiles in hospitals can thus be an important source of microbes contributing to endogenous, indirect-contact, and aerosol transmission of nosocomial related pathogens.

We hypothesize that the use of antimicrobial textiles, especially in those textiles that are in close contact with the patients, may significantly reduce bioburden in clinical settings and consequently reduce the risk of nosocomial infections. These textiles should possess broad spectrum biocidal properties. They should be safe for use and highly effective against antibiotic resistant micro-organisms, including those that are commonly involved in hospital-acquired infections, and they should not permit the development of resistant micro-organisms to the active compound.

Background

A nosocomial, or hospital-acquired, infection is a new infection that develops in a patient during hospitalization. Nosocomial infections can be bacterial, viral, fungal, or even parasitic. The most common pathogens include staphylococci (especially *Staphylococcus aureus*), *Pseudomonas*, and *Escherichia coli*. Nosocomial infections are estimated to occur in at least 5% of all patients hospitalized [1]. For example, in the United States alone, nearly two million patients annually contract an infection while being treated for another illness or injury. Nosocomial infections rank fourth among causes of death in the United States only behind heart disease, cancer and stroke [2]. In Italy, about 6.7% of hospitalized patients in the year 2000 contracted an infection while hospitalized

* Corresponding author. Present address: Hameyasdim 44, Kfar Gibton, 76910, Israel. Tel.: +972 546 611287, +1 866 317 4670 (from USA); fax: +972 8 9491254.

E-mail address: gadi@cupron.com (G. Borkow).

0306-9877/$ - see front matter
doi:10.1016/j.mehy.2007.08.025

[3]; and in England, the percentage of infections that occurred at the site of operation during several surgical procedures conducted between October 1997 and June 2001 in 140 hospitals reached up to 14.3% [4]. The rates of nosocomial infections in developing countries are even higher [5,6].

Many of the pathogens that cause nosocomial infections have a high level of resistance to antibiotic treatments. These emerging pathogens are the most serious concerns, because they are more difficult to treat. The emergence of antibiotic resistance micro-organisms (e.g. of *S. aureus* [7]) are increasing extremely rapidly around the globe, creating a serious threat to the spread and treatment of infectious diseases. For example, the prevalence of methicillin-resistant *S. aureus* (MRSA) was less than 5% in most hospitals worldwide in the early 1970s but a decade later had increased to as much as 40% in many hospitals in the United States and Europe [8,9]. The more common resistance micro-organisms in health care facilities include, in addition to MRSA, vancomycin-resistant enterococci (VRE) and enteric gram-negative bacilli (*Klebsiella* and *Enterobacter* species) resistant to an extended-spectrum of β-lactams [10]. Nosocomial infections together with the alarming increase in antibiotic resistant micro-organisms may thus be considered a worldwide crisis and an evolving pandemic.

The airborne transmission of infection in hospital buildings

It is recognized that the most important and frequent mode of transmission of nosocomial infections is through direct-contact between a susceptible host and an infected or colonized person. Direct-contact transmission may occur between two patients, with one serving as the source of the infectious micro-organisms and the other as a susceptible host. However, direct-contact is mainly attributed to healthcare workers that do not wash their hands effectively before attending patients [11,12]. Additionally, susceptible hosts may be infected indirectly via contaminated intermediate objects, usually inanimate, such as contaminated instruments, needles, dressings, or contaminated gloves [13]. Importantly, most common nosocomial pathogens may persist on surfaces for months and can thereby be a continuous source of transmission [14]. Finally, another form of contact-spread is via endogenous transmission of the patient's own flora from one part of the host's body to another [15].

Although many nosocomial infections are associated with person-to-person contact, much data is accumulating in support of the notion that airborne transmission of bacteria contributes significantly to hospital-acquired infections [16]. Airborne transmission refers to infections which are contracted from micro-organisms which have become airborne, usually from coughing, sneezing or some other form of aerosolization. However, it can equally apply to dust particles and skin squamae carrying pathogenic micro-organisms. Contaminated objects include the floor, bed linens, the patient's gown, over-bed tables, and blood pressure cuffs [16].

Indeed, it has been estimated that the airborne route of transmission accounts for between 10 and 20% of endemic nosocomial infections [17]. Airborne transmission is known to be the route of infection for diseases such as tuberculosis and aspergillosis [16]. Recently it has been implicated in nosocomial outbreaks of *S. aureus* and MRSA in operating theatres, intensive care, burns and orthopaedic units [18–20]. For example, Rutala et al. [20] investigating an MRSA outbreak, found that MRSA comprised 16% of all bacterial isolates sampled from the air and 31% of the isolates from elevated surfaces. Since it is unlikely that healthcare personnel or patients ever touch elevated surfaces, the presence of MRSA isolates on these surfaces suggested that staphylococci may be transported through the air.

A study by Noble et al. [21] found that the size distribution of particles in air containing *S. aureus* was approximately 4–25 mm, which is roughly the size of skin squamae and well in excess of the size of single *S. aureus* cells (i.e. about 1 mm diameter). Noble et al. therefore surmised that most of the airborne *S. aureus* organisms were carried on skin squamae. Humans liberate approximately 3×10^8 squamae per day. Noble et al. [21] concluded that in many people a closed loop exists; contaminated skin squamae are released into the air; they become impacted on the nasal turbinates; *S. aureus* grows on the nasal mucosa; hands then touch the nose and *S. aureus* bacteria are transferred to the skin; they colonize the skin and are ultimately disseminated back into the air on skin squamae.

Aerosol transmission of other bacteria, such as *Acinetobacter baumannii* [22–24], *Pseudomonas aeruginosa* [25], and other *Staphylococci* spp. [26] in hospital settings has also been reported. Furthermore, Kelsen and McGuckin [27] found a significant correlation between the monthly rate of nosocomial respiratory tract infection and the average bacterial count in the ward air. Fungal spores are also widely disseminated via the airborne route. *Aspergillus fumigatus* spores, for

example, often enter hospital buildings through open windows or through mechanical ventilation ducts. Immune-compromised patients are particularly vulnerable to infection from *A. fumigatus*. Indeed, case fatality rates of 85% are typical amongst bone marrow transplant recipients [28]. Similarly, airborne *Scedosporium prolificans* nosocomial infection was reported in Spain [28].

Textiles as a source of bacteria in clinical settings

Textiles are an excellent substrate for bacterial and fungal growth under appropriate moisture and temperature conditions. Microbial growth in textiles can cause foul odours and damage to the textiles, such as discoloration. In a clinical setting, they can be an important source of bacteria that may contaminate the patients and personnel and the direct and indirect environment (as discussed below). Bacteria are normally found on human skin, nasal cavities, and other areas, such as in the genitalia area. At any one time, for example, approximately 30% of healthy people are carriers of *S. aureus* [16]. Microbial shedding from our body occurs all the time [21]. When a bacterium is shed into a textile fabric between the patient and the bed, either in his pyjama or directly on the sheet, the moisture and temperature in the textile micro-environment promotes its proliferation. Bacterial shedding is greater in patients. For example, Coronel et al. [29] found that bacteria recovered from the sheets were significantly higher in patients carrying infection than in non-infected patients. The infected patients had 711 ± 465 colony forming units (CFU)/25 cm^2 sheets versus 438 ± 496 CFU/25 cm^2 ($p < 0.01$). The back and the feet were showing the largest differences between infected and non-infected patients: 578 ± 397 CFU/25 cm^2 versus 368 ± 500 CFU/25 cm^2 and 872 ± 479 versus 347 ± 429 CFU/25 cm^2, respectively. Similarly, in a study at the Barzilai Hospital in Israel, bacterial colonization of sheets, including MRSA, has been found in 22 out of the 30 sheets examined, with an average of $21{,}909 \pm 3134$ CFU/100 cm^2 [30]. Increased bacterial shedding from nasal cavities has been reported for patients with upper respiratory infections [16].

Importantly, it was found that bed making releases large quantities of micro-organisms into the atmosphere. Greene et al. [31] found that the total viable count (TVC) in a patient room exceeded 6000 CFU/m^3 of air during vigorous bed making, which was more than 10-fold higher than the background levels of bacteria found in the air prior to the bed making. Interestingly, they also found approximately two fold increase in the TVC in the hallways following bed making. The bacterial count in the air fell back to background levels only 30 min after bed making. The data for the hallway also reveals that the bed making process dispersed micro-organisms around the building.

In a similar study, Shiomori et al. [32] measured the number of MRSA in the air and in various surfaces before, during and after bed making. They found a 25—26-fold increase ($p < 0.01$) in the number of MRSA in the air immediately following bed making. The bacteria levels in the air fell back to background levels within 30 min. MRSA was detected following the bed making also on many surfaces, such as bed sheets, over-bed tables, and patients' clothing.

Similarly, Solberg [33] found strong positive correlation between the air counts of staphylococci and the making of the beds of his patients. He reported that bed making of at least 20% of the 2014 patients surveyed dispersed more than 10,000 staphylococcus-carrying particles into the air. Similar results were reported by Noble and Davies [34] in patients following undressing and redressing.

These studies strongly support the notion that disturbance of textiles in clinical settings may contribute to the dispersal of pathogens to the air, which then settle down and contaminate the immediate and non-immediate environment. Healthcare workers that touch pathogens in aerosol contaminated surfaces can then transport these pathogens to patients by the contact route. Indeed, the source of contamination in 21.1% of 1561 nosocomial outbreaks studied has been attributed to contaminated surfaces [13].

Contaminated textiles, such as contaminated sheets and pyjamas, in addition to be a source of aerosol transmission of micro-organisms, can also directly contaminate the hospital personnel. For example, the CDC reported that MRSA spread also occurred though indirect-contact by touching objects such as towels, sheets, wound dressings and clothes contaminated by the infected skin of a person with MRSA [35]. Similarly, it has been shown that 42% of personnel who had no direct-contact with patients, but had touched different surfaces including bed linens, contaminated their gloves with MRSA [36]. An investigation of a nosocomial infection in Japan revealed that transmission of *S. pyogenes* occurred via contact with the contaminated surface of a vinyl sheet that covered the bed on which the patients were treated [37]. Similarly, an investigation regarding a nosocomial outbreak of *Norwalk gastroenteritis* revealed that bedding was a significant risk factor [38,39].

Hospital staff, even by using protective equipment such as gloves, can contaminate them by touching the contaminated textiles and then transfer the micro-organisms to other patients directly or indirectly by contaminating other surfaces, such as door knobs. For example, it was found that 65% of the nurses who performed activities on patients with MRSA in wounds or urine, contaminated their nursing uniforms or gowns with MRSA. This in turn, will readily contaminate the clothing and hands of healthcare workers [16,36].

Prevention of nosocomial infections

Nosocomial infections can significantly be reduced and guidelines for preventing healthcare-associated infections are being established (e.g. [40]). It is estimated that by using several strategies simultaneously about one third of these infections may be eliminated [10,41]. These strategies include improvement of national surveillance of nosocomial infections, using valid surveillance parameters; improving the design of invasive devices that may avoid the high risk associated with bypassing normal host defence barriers (e.g., the skin and mucous membranes); use of aggressive antibiotic control programs to reduce the spread of antibiotic resistant strains; increase hospital hygiene; hand hygiene; use of personal protective equipment and successful collaboration of the infection control community, CDC, and regulatory agencies. The goals are to avoid pathogen transmission by hand, by air and by blood. It is widely agreed that hand washing is the most important method to decrease nosocomial infection in the hospital setting [42,43], but, sadly, this hygiene action is often lacking [10,12,11]. Other measures include avoiding hand contact, especially to the conjunctiva or nasal areas. Various sterilization measures are helpful ranging from simple acts like sterilizing ventilators to full scale air filtering systems in the hospital.

However, in spite of all the above mentioned measures, the control of nosocomial infections still remains a challenge to the infectious control community and novel and additional measures to fight nosocomial infectious have to be considered. It is clear that the current modalities to reduce nosocomial infections are not sufficient.

Our hypothesis

We hypothesize that the fabrics that are in contact with patients are an important source of micro-organisms that may infect susceptible patients either by endogenous transmission, indirect-contact or through airborne transmission when these fabrics are handled by the hospital staff. We submit that by making the hospital textiles, especially those that come in contact with the patients, such as patient's sheets, pillowcases, robes, and pyjamas, with materials that have potent biocidal properties, would help reduce an important source of micro-organisms involved in nosocomial infections. Indeed, a pilot study with 30 patients, who slept overnight on regular-sheets and then overnight on sheets containing copper-oxide, a potent biocide, demonstrated a statistically significant lower bacterial colonization on the copper-oxide containing sheets than on regular-sheets [30], strongly supporting our hypothesis.

The biocidal materials introduced into the hospital textiles should have the following key characteristics:

- Have wide spectrum antimicrobial, antifungal and antiviral properties.
- Be effective against the already existent antibiotic resistant micro-organisms involved in nosocomial infections.
- Not permit the development of micro-organisms which are resistant to the active component.
- Do not cause skin irritation or sensitization.
- Be safe to humans.

As nosocomial infections are now also spreading out from the hospital environment into the community (e.g. [44]), the use of textiles, such as those impregnated with copper-oxide, which possess the above mentioned properties, may not only significantly contribute to the reduction of hospital-acquired infections, but may also confer protection when used in homes for the elderly and in other environments where immune-compromised individuals are at high risk of contracting infections.

References

[1] Nguyen QV. Hospital-acquired infections. 2006, http://www.emedicine.com/ped/topic1619.htm.
[2] Klevens RM, Edwards JR, Richards Jr CL, et al. Estimating health care-associated infections and deaths in US hospitals, 2002. Public Health Rep 2007;122:160—6.
[3] Eric Jozsef. *L'Italie scandalis'e par «l'hopital de l'horreur»*. Liberation. January 15, 2007.
[4] Coello R, Charlett A, Wilson J, Ward V, Pearson A, Borriello P. Adverse impact of surgical site infections in English hospitals. J Hosp Infect 2005;60:93—103.
[5] Joshi R, Reingold AL, Menzies D, Pai M. Tuberculosis among health-care workers in low- and middle-income countries: a systematic review. PLoS Med 2006;3:e494.
[6] Hughes AJ, Ariffin N, Huat TL, et al. Prevalence of nosocomial infection and antibiotic use at a university medical center in Malaysia. Infect Control Hosp Epidemiol 2005;26:100—4.

[7] Lowy FD. Antimicrobial resistance: the example of *Staphylococcus aureus*. J Clin Invest 2003;111:1265—73.
[8] Voss A, Milatovic D, Wallrauch-Schwarz C, Rosdahl VT, Braveny I. Methicillin-resistant *Staphylococcus aureus* in Europe. Eur J Clin Microbiol Infect Dis 1994;13:50—5.
[9] Panlilio AL, Culver DH, Gaynes RP, et al. Methicillin-resistant *Staphylococcus aureus* in US hospitals, 1975-1991. Infect Control Hosp Epidemiol 1992;13:582—6.
[10] Weinstein RA. Nosocomial infection update. Emerg Infect Dis 1998;4:416—20.
[11] Kampf G, Kramer A. Epidemiologic background of hand hygiene and evaluation of the most important agents for scrubs and rubs. Clin Microbiol Rev 2004;17:863—93.
[12] Ayliffe GA, Babb JR, Davies JG, Lilly HA. Hand disinfection: a comparison of various agents in laboratory and ward studies. J Hosp Infect 1988;11:226—43.
[13] Gastmeier P, Stamm-Balderjahn S, Hansen S, et al. Where should one search when confronted with outbreaks of nosocomial infection? Am J Infect Control 2006;34:603—5.
[14] Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. BMC Infect Dis 2006;6:130.
[15] Kropec A, Huebner J, Riffel M, et al. Exogenous or endogenous reservoirs of nosocomial *Pseudomonas aeruginosa* and *Staphylococcus aureus* infections in a surgical intensive care unit. Intensive Care Med 1993;19:161—5.
[16] Beggs CB. The airborne transmission of infection in hospital buildings: fact or fiction? Indoor Built Environ 2003;12:9—18.
[17] Brachman PS. Nosocomial respiratory infections. Prev Med 1974;3:500—6.
[18] Walter CW, Kundsin RB, Brubaker MM. The incidence of airborne wound infection during operation. JAMA 1963;186:908—13.
[19] Farrington M, Ling J, Ling T, French GL. Outbreaks of infection with methicillin-resistant *Staphylococcus aureus* on neonatal and burns units of a new hospital. Epidemiol Infect 1990;105:215—28.
[20] Rutula WA. Environmental study of a methicillin-resistant *Staphylococcus aureus* epidemic in a burn unit. J Clin Microbiol 1983;18:683—8.
[21] Noble WA. Dispersal of microorganisms from skin. In: Microbiology of human skin. London: Lloyd-Luke Ltd.; 1981. p. 77—85.
[22] Bernards AT, Frenay HM, Lim BT, Hendriks WD, Dijkshoorn L, van Boven CP. Methicillin-resistant *Staphylococcus aureus* and *Acinetobacter baumannii*: an unexpected difference in epidemiologic behavior. Am J Infect Control 1998;26:544—51.
[23] Allen KD, Green HT. Hospital outbreak of multi-resistant *Acinetobacter anitratus*: an airborne mode of spread? J Hosp Infect 1987;9:110—9.
[24] Cox RA, Conquest C, Mallaghan C, Marples RR. A major outbreak of methicillin-resistant *Staphylococcus aureus* caused by a new phage-type (EMRSA-16). J Hosp Infect 1995;29:87—106.
[25] Mortimer Jr EA, Wolinsky E, Gonzaga AJ, Rammelkamp Jr CH. Role of airborne transmission in staphylococcal infections. Br Med J 1966;1:319—22.
[26] Lidwell OM, Lowbury EJ, Whyte W, Blowers R, Stanley SJ, Lowe D. Effect of ultraclean air in operating rooms on deep sepsis in the joint after total hip or knee replacement: a randomised study. Br Med J (Clin Res Ed) 1982;285:10—4.
[27] Kelsen SG, McGuckin M. The role of airborne bacteria in the contamination of fine particle neubilizers and the development of nosocomial pneumonia. Ann N Y Acad Sci 1980;353:218—29.
[28] Walter EA, Bowden RA. Infection in the bone marrow transplant recipient. Infect Dis Clin North Am 1995;9:823—47.
[29] Coronel D, Escarment J, Boiron A, et al. Infection et contamination bacterienne de l'environnement des patients: les draps. Reanimation 2001;10S:43—4.
[30] Gabbay J, Mishal J, Magen E, Zatcoff RC, Shemer-Avni Y, Borkow G. Copper oxide impregnated textiles with potent biocidal activities. J Ind Textiles 2006;35:323—35.
[31] Greene VW, Bond RG, Michaelsen GS. Air handling systems must be planned to reduce the spread of infection. Mod Hosp 1960;95:136—44.
[32] Shiomori T, Miyamoto H, Makishima K, et al. Evaluation of bedmaking-related airborne and surface methicillin-resistant *Staphylococcus aureus* contamination. J Hosp Infect 2002;50:30—5.
[33] Solberg CO. A study of carriers of *Staphylococcus aureus* with special regard to quantitative bacterial estimations. Acta Med Scand Suppl 1965;436:1—96.
[34] Noble WC, Davies RR. Studies on the dispersal of *Staphylococci*. J Clin Pathol 1965;18:16—9.
[35] CDC. Fact Sheet. 2007, http://www.cdc.gov/ncidod/hip/Aresist/mrsafaq.htm.
[36] Boyce JM, Potter-Bynoe G, Chenevert C, King T. Environmental contamination due to methicillin-resistant *Staphylococcus aureus*: possible infection control implications. Infect Control Hosp Epidemiol 1997;18:622—7.
[37] Takahashi A, Yomoda S, Tanimoto K, Kanda T, Kobayashi I, Ike Y. Streptococcus pyogenes hospital-acquired infection within a dermatological ward. J Hosp Infect 1998;40:135—40.
[38] Gustafson TL, Kobylik B, Hutcheson RH, Schaffner W. Protective effect of anticholinergic drugs and psyllium in a nosocomial outbreak of Norwalk gastroenteritis. J Hosp Infect 1983;4:367—74.
[39] http://www.outbreak-database.com, 2007.
[40] Pratt RJ, Pellowe CM, Wilson JA, et al. Epic2: national evidence-based guidelines for preventing healthcare-associated infections in NHS hospitals in England. J Hosp Infect 2007;65(Suppl 1):S1—S64.
[41] Scheckler WE, Brimhall D, Buck AS, et al. Requirements for infrastructure and essential activities of infection control and epidemiology in hospitals: a consensus panel report. Society for Healthcare Epidemiology of America. Infect Control Hosp Epidemiol 1998;19:114—24.
[42] McGuckin M, Waterman R, Porten L, et al. Patient education model for increasing hand washing compliance. Am J Infect Control 1999;27:309—14.
[43] Pittet D, Hugonnet S, Harbarth S, et al. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. Infection Control Programme. Lancet 2000;356:1307—12.
[44] Olesevich M, Kennedy A. Emergence of community-acquired methicillin-resistant *Staphylococcus aureus* soft tissue infections. J Pediatr Surg 2007;42:765—8.