Preventing Pathogens Proliferation and Reducing Potential Sources of Nosocomial Infections with Biocidal Textiles in Developing Countries

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Abstract: Nosocomial infections, especially those caused by antibiotic resistant bacteria, are increasing at an alarming rate over the globe. Unfortunately, standard infection control practices, such as pre-emptive isolation of high-risk patients, wide and targeted surveillance cultures, and proper ventilation systems are lacking in developing countries mainly due to insufficient resources.

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. Bed making releases large quantities of micro-organisms into the air, which contaminate the immediate and non-immediate surroundings. Personnel in contact with contaminated textiles can also cross-contaminate other surfaces or patients. Thus textiles in hospitals can be an important source of microbes contributing to endogenous, indirect-contact, and aerosol transmission of nosocomial related pathogens.

The use of safe wide-spectrum 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. This is of special significance in resource poor developing countries, where wards are overcrowded and population infection burdens are very high. The use of biocidal textiles is a simple, cost-affordable and feasible measure that may be especially important in developing countries where essential infection control measures are not implemented.

Keywords: Nosocomial infections, textiles, biocides, developing countries.

BACKGROUND

Nosocomial infections (NI) pose a critical threat to patients. Even in countries where extensive infection control measures are routinely implemented, the risk of contracting a NI is very high. For example, in the USA during 2002 alone approximately 1.7 million patients contracted a NI while hospitalized, of which almost 100,000 died [1]. In Switzerland and in Italy approximately 1 out of each 20 and 1 out of each 10 hospitalized patients contracted a NI during 1996 and 2000, respectively [2,3]. In Germany the annual number of NI estimated for 2006 is between 400,000 and 600,000 and the mortality attributable to them between 10,000 and 15,000 patients [4].

In developing countries infection control and NI prevalence reports are often not well established because of the lack of centralized guidelines, staff and resources [5]. However, based on some existing reports, it is clear that the risks of contracting a NI in a clinical setting in developing countries are even higher than those reported in developed countries. For example, in a Moroccan university hospital, almost 2 out of each 10 hospitalized patients contracted a NI [6]. Similar results were found in a Tunisian hospital [7]. The risk of contracting a NI in a high-risk department, such as in the Intensive Care Unit (ICU), is alarming especially in developing countries where the reported rates varied from 14% to almost 75% [6, 8-16]. The mean rate of just device-associated NI observed in 55 ICUs in Argentina, Brazil, Colombia, India, Mexico, Morocco, Peru, and Turkey was 14.7% [17]. The rates of NI in other hospital wards in developing countries are also very high; e.g., almost 10% in a general surgery department of a teaching hospital in Bamako, Mali [18], 12% in a general surgical ward in Santa Cruz, Bolivia [19] and 14% and 50% in tertiary care centers in Malaysia [20,21] and Kenya [22], respectively.

The emergence of antibiotic resistant micro-organisms (e.g., *Staphylococcus aureus* [23,24]) is increasing extremely rapidly around the globe, creating a serious threat to the spread and treatment of infectious diseases. Many of the pathogens that cause NI have a high level of resistance to antibiotic treatments (e.g., [25]). For example, an increase of the methicillin resistant *S. aureus* (MRSA) rate from 8% in 1997 to 26.9% in 2002 [26] and from 19.8% in 2000 to 37.2% in 2005 [27] in German ICUs was reported. Furthermore, it has been estimated that among the 15,000 deaths attributed to NI in 2006, 14,000 were caused by MRSA [4]. Similarly, the proportion of MRSA increased from 22% in 1995 to 57% in 2001 as determined in 49 US hospitals [28]. Disturbingly, new molecular clones resistant to MRSA continue to appear [29].

The problem of antimicrobial resistance is even graver in developing countries [30]. For example, in 12 ICUs in seven Indian cities, overall 87.5% of all *S. aureus* healthcare-associated infections were caused by methicillin-resistant strains, 71.4% of *Enterobacteriaceae* were resistant to ceftriaxone and 26.1% to piperacillin-tazobactam; 28.6% of

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the *Pseudomonas aeruginosa* strains were resistant to ciprofloxacin, 64.9% to ceftazidime and 42.0% to imipenem [31]. Similarly, among the causative pathogens involved in NI in a Thai ICU, the proportion of MRSA, imipenem-resistant *P. aeruginosa*, ceftazidime-resistant *Acinetobacter baumannii*, third-generation-cephalosporin-resistant *Klebsiella pneumoniae*, and quinolone-resistant *Escherichia coli* was 68.8%, 30.9%, 68.5%, 44.6%, 38.3%, respectively [32]. Similar high percentages of antibiotic resistant isolates involved in NI were reported for Peru [33].

In addition, in developing countries the infectious disease burden is high [34-38] and cost constraints prevent the widespread application of newer, more expensive and efficacious antimicrobial agents [39]. Furthermore, the implementation of basic infection control measurements, such as hand washing and personnel training, are lacking in many hospitals in limited resources countries (e.g., [40]). It was found that even after 11 years of implementing process surveillance intervention in 77 ICUs in 14 developing countries, ~ 40% of the ICU healthcare workers do not comply with hand-washing guidelines [41].

An important and frequent mode of transmission of pathogens causing NI is through cross-contamination between a susceptible host and an infected or colonized person (e.g., [42,43]). Cross-contamination is mainly attributed to healthcare workers that do not wash their hands effectively before attending patients or do not change gloves between patients [44,45]. However, even when there is acute awareness of the source of pathogen transmission and generally good infection control measures are undertaken in a given department to avoid further spread of NI related pathogens from a particular identified source, continued NI from that source was shown to nevertheless occur [46]. Susceptible hosts may also be infected indirectly via contaminated intermediate objects, usually inanimate, such as contaminated instruments, needles or dressings [47,48]. Airborne transmission of bacteria and viruses may also contribute significantly to hospital acquired infections [49-51]. While 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, 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, overbed tables, and blood pressure cuffs [49]. Airborne transmission of bacteria has been implicated in nosocomial outbreaks of *S. aureus* and MRSA [52-55], *A. baumannii* [56-58], *P. aeruginosa* [59], and other *Staphylococci spp* [60] in operating theaters, intensive care, burns and orthopaedic units. Furthermore, a significant association has been found between the monthly rate of nosocomial respiratory tract infection and the average bacterial count in the ward air [61]. Airborne transmission is known to be the route of infection for diseases such as tuberculosis [49], which is an occupational risk hazard among healthcare workers in developing countries [62]. At the same time, airborne transmission in hospitals of fungi, such as *Aspergillus* [63] and *Scedosporium prolificans*, has been documented [63]. Importantly, most common nosocomial pathogens may persist on surfaces for months, including on hospital fabrics [64-66], and can thereby be a continuous source of transmission [67]. 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 [68].

PROLIFERATION OF BACTERIA IN TEXTILES – A HIDDEN IMPORTANT SOURCE OF PATHOGENS IN CLINICAL SETTINGS

Textiles, including hospital fabrics [64-66], are an excellent substrate for bacterial and fungal growth under appropriate moisture and temperature conditions. Bacteria are normally found on human skin, nasal cavities, and other areas, such as the genitalia. At any one time, for example, approximately 30% of healthy people are carriers of *S. aureus* [49].

Microbial shedding from our body occurs all the time [55] and is greater in patients [49,69-71]. When a bacterium is shed into a textile fabric between the patient and the bed, either on his pyjama or directly on the sheet, the moisture and temperature in the textile microenvironment promote its proliferation. This is indicated by the fact that bacterial colonization of sheets, including MRSA, has been found in 22 out of the 30 sheets examined in a clinical setting, with an average of 21909 ± 3134 (mean ± SD) CFU/100cm^2 [72]. Importantly, it was found that bed making releases large quantities of micro-organisms into the air. For example, it was 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 [73]. There was also a two-fold increase in the TVC in the hallways following bed making, indicating that the bed making process dispersed micro-organisms around the building. The bacterial count in the air fell back to background levels only 30 min after bed making (Fig. **1a**). In a similar study, the number of MRSA in the air and in various surfaces before, during and after bed making was determined. It was found that the number of MRSA in the air immediately following bed making increased by 25-26 fold (Fig. **1b**; $p<0.01$) [74]. In this case too, bacteria levels in the air fell back to background levels within 30 minutes. MRSA was also detected on many surfaces following bed making, including bed sheets, overbed tables, and patients' clothing. A strong positive association between the air counts of staphylococci and the making of the beds was found in another study [75] where bed making of at least 20% of the 2,014 patients surveyed dispersed more than 10,000 staphylococcus-carrying particles into the air. Similar results were reported in patients following undressing and redressing [76].

Therefore, we recently hypothesized that textiles in clinical settings are an important source of bacteria involved in NI [77]. Contaminated textiles, such as contaminated sheets and pyjamas, in addition to being a source of aerosol transmission of micro-organisms, can also directly contaminate hospital personnel, as demonstrated by numerous reports and studies. For example, the CDC reported that MRSA spread also occurred through indirect contact as a result of touching objects such as towels, sheets, wound dressings and clothes contaminated by the infected skin of a person with MRSA [78]. Similarly, it has been shown that 42% of personnel who had no direct contact with patients, but had touched different

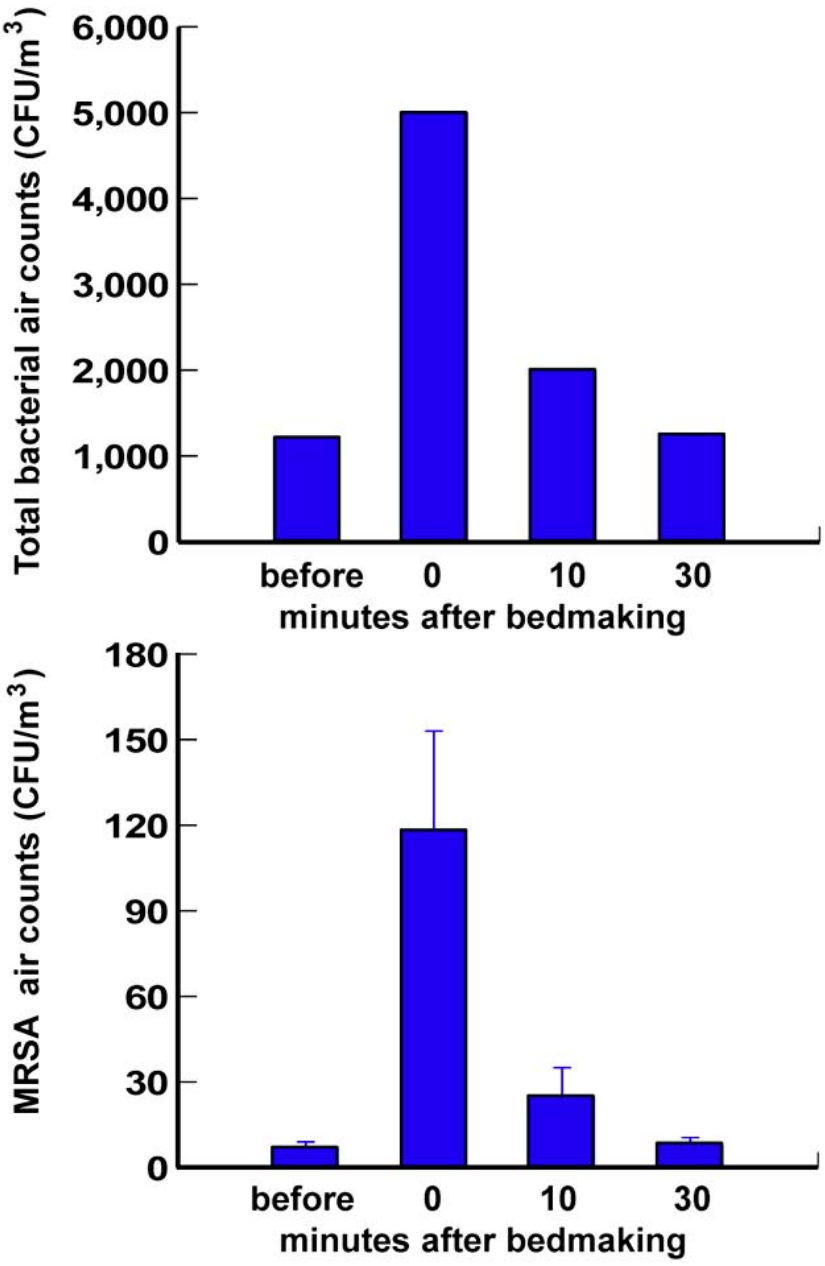

Fig. (1). Contamination of air with bacteria in hospital settings during bedmaking. **a**) Data from reference [73]. **b**) Data from reference [74].

surfaces including bed linens, contaminated their gloves with MRSA [79]. An investigation of a nosocomial infection in Japan revealed that transmission of *Streptococcus pyogenes* occurred via contact with the contaminated surface of a vinyl sheet that covered the bed on which the patients were treated [80]. Similarly, an investigation regarding a nosocomial outbreak of *Norwalk gastroenteritis* revealed that bedding was a significant risk factor [81]. Hospital staff, even when using protective equipment such as gloves, can contaminate them by touching the contaminated textiles and can then transfer the micro-organisms to other patients directly or indirectly by contaminating other surfaces, such as door knobs. Indeed, the source of contamination in 21.1% of 1561 nosocomial outbreaks studied has been attributed to contaminated surfaces [47]. 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 [49,79].

PREVENTION OF NOSOCOMIAL INFECTIONS IN DEVELOPING COUNTRIES

Nosocomial infections, including those caused by antibiotic resistant bacteria, can significantly be reduced by applying various measures (e.g., [82-88]). These measures 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 resis-

tant strains; increased hospital hygiene; improved hand hygiene; use of personal protective equipment; staff training; successful collaboration of the infection control community and regulatory agencies; isolation of high risk or contaminated patients; and reduction in the number of patients per room in hospital wards.

Unfortunately, in many developing countries, such as in African countries, which have a massive infectious disease burden and very high rates of chronic diseases [30,35-38], isolation of infected patients or many of the above mentioned interventions are often not implementable or practical. For example, overcrowding in wards does not allow for cohorting or isolation of respiratory syncytial virus (RSV) infected children in some general wards in sub-Saharan African countries, where the high prevalence of HIV-1 infection among the hospitalized children (~ 40%) [89] combined with the prolonged shedding of RSV among HIV-1 infected children [70,71] significantly increase the risk of nosocomial transmission of RSV [51]. In addition, most African countries lack appropriate human resources, do not have regional or hospital infection surveillance programs [5] and are unequipped with infrastructure to handle surveillance of the new resistant bacterial strains resulting from indiscriminate use of antibiotics [90].

Obviously, clear and well established measures to control NI, which have been found to reduce the rates of NI in many hospitals, have to be implemented worldwide, including in developing countries. However, in spite of all the above mentioned measures, even when all are implemented, NI continue to occur, requiring the consideration of novel and additional measures to fight NI. It is clear that the current modalities to reduce nosocomial infections are not sufficient. The problem in resource poor countries is even further magnified by the lack of appropriate human and infrastructure resources. Thus, in addition to essential feasible infection control measures that should be strictly implemented in all clinical settings, such as hand washing, other simple, feasible and practicable measures should be implemented especially in developing countries.

We suggest that hospital textiles, especially those that come in contact with the patients, such as patients' sheets, pillowcases, robes, and pyjamas, 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. Hospital textiles are used in any case in clinical settings, including in developing countries. We submit that by making these hospital textiles from materials that have potent wide spectrum biocidal properties, an important source of micro-organisms involved in nosocomial infections would be reduced. Safe biocidal textiles, with wide spectrum antimicrobial, antifungal and antiviral properties do exist (e.g., [72,91,92]) and can be mass produced. The use of biocidal textiles is a simple, cost-affordable and feasible measure that may be especially important in developing countries where essential infection control measures are not implemented. Production of biocidal hospital textiles does not cost significantly more than the production of regular current hospital textiles and thus they should be feasible for acquisition in developing countries. Obviously the biocidal materials introduced into the hospital textiles should be effective against the already existing antibiotic resistant micro-organisms involved in nosocomial infections, and should not permit the development of micro-organisms which are resistant to the active component. In any case, the reduction of NI due to the use of such textiles would reduce prolonged hospitalization, decrease the use of antibiotics and the very high costs associated with NI management and prevention, and possibly alleviate suffering while saving the lives of many.

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