Promises and pitfalls of recent advances in chemical means of preventing the spread of nosocomial infections by environmental surfaces

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Hard, nonporous environmental surfaces in health care settings are now receiving due recognition for their role in the spread of several types of nosocomial pathogens. The corresponding increase in the means to decontaminate such surfaces to interrupt the spread of infections is leading to the marketing of a plethora of products and procedures, including the ''green'' variety, with varying claims of microbicidal activity, human and environmental safety, and materials compatibility. Limitations of the existing methods to assess environmental surface disinfectants and the regulations that govern their premarket registration make objective evaluations difficult. Label claims of many such products also do not reflect the realities of field use along with a strong tendency to focus on the ''bug de jour.'' Furthermore, whereas wiping is often an integral part of environmental surface decontamination, products meant for the purpose are rarely assessed with the physical effect of wiping incorporated. Many ''green'' products possess neither the spectrum of microbicidal activity nor the speed of action essential for use in health care settings. In general, ''self-sanitizing'' surfaces being marketed actively these days require greater scrutiny for field-relevant microbicidal activity as well as the potential to enhance microbicide resistance. The widening use of environmental surface disinfectants is also raising concerns on their human and environmental safety at many levels along with the realization that routine surface disinfection procedures in health care settings are frequently inadequate and possibly counterproductive. All this points to an urgent review of the basic procedures for assessing existing and new environmental surface disinfectants for their microbicidal activity, label claims, registration requirements, overall safety, and routine practices of environmental surface decontamination.

Key Words: Infection control; disinfection; microbicides; microfibers; self-sanitizing surfaces; nosocomial pathogens; infection prevention; environmental surfaces.

The onslaught of infectious agents on human health continues essentially unabated.[1] In fact, and quite paradoxically given the increased efforts for their elimination, the health threats from many infectious agents keep rising because of a variety of factors unique to our societies today.[2,3] In spite of this, and notwithstanding the otherwise impressive gains in health sciences in general, our understanding of the means of transmission of many common communicable diseases remains rather sparse.[4] For example, 2 recent reviews[5,6] on transmission of influenza viruses in human populations reached opposite conclusions even though influenza per se has been around for millennia with periodic epidemics and pandemics of truly epic proportions.[7]

One welcome development in all this is an overdue revival of interest in the role of the environment in general in the spread of several common types of human pathogens.[8] More specifically, *environmental surfaces* are now receiving due recognition as potential vehicles for numerous nosocomial pathogens along with the ensuing emphasis on environmental decontamination for infection prevention.[9-14] In part, this new recognition has derived from a perceived marketing opportunity by those who manufacture and sell disinfectants, and the intense competition in the marketplace is leading to a bewildering array of claims of effectiveness and safety. As a consequence, we are being deluged with information on ''new'' infection prevention products and

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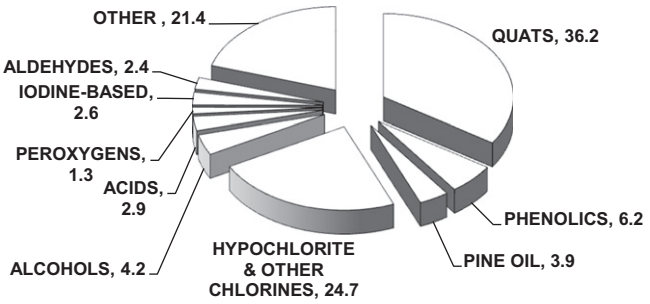

Fig 1. Chemicals used as disinfectants in institutional and industrial settings in the United States (modified from Fu et al[15]).

processes, with little time, opportunity, or resources to assess properly the veracity of their claims.

In addition, the ''green'' movement has gained much strength and popularity in recent years. Although this is certainly a good thing overall, much is being marketed as ''green'' for infection prevention, again without sufficiently rigid criteria and proper evidence for meaningful microbicidal activity in particular.

This review will critically assess selected aspects of recent developments in chemical disinfection of environmental surfaces in health care settings. Antisepsis and disinfection/sterilization of medical devices are beyond its scope.

CURRENTLY USED DISINFECTANT CHEMICALS

As shown in Fig 1, we continue to use a wide array of chemicals as disinfectants, many to disinfect hard, nonporous environmental surfaces in industrial and institutional settings.[15] Such use is largely based on history and tradition and much less on proven effectiveness of those chemicals in the field. Also, it is worth reiterating here that, all things considered equal, the microbicidal activity of any disinfectant is inversely proportional to the degree of soiling of the target surface and that laboratory-based testing of such disinfectants often gives only *an indication* of their performance in the field. Moreover, recent years have seen mounting concerns on the overall safety of several disinfectant chemicals[16] and their potential to contribute to the already serious problem of antibiotic resistance.[17-19] Many state,[20] national,[21,22] and regional[23] as well as advocacy groups[24] are also now quite active in attempts to reduce the environmental loadings of many potentially harmful chemicals. These manifestations of much needed political will and public awareness, and better regulations accompanying them, are bound to impact our selection and use of disinfectant chemicals in general. All this is forcing a major rethink of what, when, and how we use disinfectants; and, if the anticipated changes do occur, the number of actives and their relative amounts will be substantially reduced in the near future.

Table 1. Four of 12 principles of ''green chemistry''

Design safer chemicals and products that are fully effective with little or no toxicity
Use safer solvents and reaction conditions
Design chemicals and products to degrade after use so that they do not accumulate
Minimize potential for accidents such as explosions, fires, and releases to the environment

NOTE. Modified from Anastas and Warner.[32]

No new and truly safe and effective environmental surface disinfectants have been marketed in the past several years. This is perhaps not surprising in view of the extensive dossiers on human and ecologic safety that must be developed these days to register a new active. Some already well-known chemicals, hydrogen peroxide as an example,[25] have been reformulated for faster action, broader spectrum of microbicidal activity, and greater materials compatibility.[26] Many other ''innovations'' represent no more than remixes of long-standing chemicals but with no substantial improvements in their speed of action and materials compatibility profile.[27] Certain newer technologies,[28] including the use of super-oxidized water,[29] do show promise, but their application to disinfect environmental surfaces requires further exploration to enhance workplace safety and reduce risks from development of microbial resistance.

''GREEN'' PRODUCTS

'Green' products made from household chemicals such as vinegar and baking soda or the ''all-natural'' ones containing plant extracts may indeed be safer as ''cleaners'' but without the speed and broad-spectrum microbicidal activity essential for routine disinfection of environmental surfaces.[30] Although certain of these products may also be government registered, that on its own does not make them suitable for use, especially in health care settings where fast and broad-spectrum microbicidal activity is a must. It has also been shown recently that certain types of botanicals can disrupt hormone function in humans.[31] This suggests caution in their more widespread use as disinfectants without properly assessing any potential risks.

However, how is one to avoid being overwhelmed by the rapidly increasing number and variety of ''green'' disinfectants? A good place to start is by looking at the now widely accepted principles for what constitutes ''green chemistry''[32]; Table 1 lists the 4 of those principles relevant to disinfectants, with the first and

Table 2. Examples of organizations promoting and certifying "green" products and technologies

Organization	Origin and mandate
Ecologo	Launched in Canada in 1988; now global
Envirodesic	Places greater emphasis on indoor air quality
EU Ecolabel	A voluntary scheme launched in Europe in 1992 to promote making and marketing of green products
Green Chemistry	A journal devoted to promoting research on safer chemicals
Green Seal	Founded in 1989; provides science-based environmental certification standards
Greenguard Institute	Founded in 2001 for third-party certification to promote indoor air quality
Sierra Club	Has been promoting environmental protection since 1972

third being particularly noteworthy because they together clearly emphasize the need for effectiveness as well as human and environmental safety by discouraging the use of persistent chemicals. Ideally, such a lack of persistence should go beyond biodegradability and entail a breakdown of the active into innocuous by-products at the point of application once the microbicidal action has been accomplished. At the moment, only suitably formulated, oxidizer-based environmental surface disinfectants come closest to meeting this criterion.

The advent of the ''green movement'' has also spawned many nongovernmental or semigovernmental organizations to promote and certify ''green'' products and technologies (Table 2). However, there are wide variations in the mandates of such organizations and perhaps a need for them to focus their criteria for defining ''green'' more in line with the fundamental requirements of ''green chemistry''[32] for greater relevance of their services to infection preventionists in health care settings.

If ''green'' products or detergents alone are regarded as generally safer, would their use for the *cleaning* of noncritical surfaces not be sufficient to reduce the use of microbicidal chemicals as such? Some consider this a valid approach for interrupting the spread of nosocomial pathogens.[33] However, for cleaning alone to be effective for the purpose, it must be routinely carried out thoroughly by well-trained personnel to avoid the risk of spreading pathogens over a wider area during the wiping of surfaces. The recent studies of Carling et al[9,34] clearly show the routine cleaning/disinfection of even critical high-touch surfaces in many hospitals to be much less than satisfactory.

WIPING OF SURFACES

Although most environmental surface disinfectants are meant for wiping surfaces, their label claims are almost always based on testing devoid of any wiping action. For an effective product applied in sufficient quantity and for an adequate contact time, the mechanical action of wiping can substantially enhance the process of decontamination. On the other hand, because decontamination cannot take place without contact for a sufficient length of time, use of too small a quantity of product and/or contact for too short a time will inevitably lead to infection control efforts being seriously undermined even when a potentially effective product is used.[35] Wiping surfaces using formulations with weak and/or limited microbicidal activity can, in fact, be counterproductive by spreading localized contamination over a wider area.[36] These issues significantly complicate the selection of disinfectant products and development of suitable disinfection protocols for health care settings.

Although efforts are now underway to deal with this long-neglected issue of wiping,[37,38] much work will be required to develop robust and standardized test protocols to simulate properly the wiping action so that the label can be as reliable and meaningful as possible. Any type of applicator for wiping of surfaces exerts its own demand on the disinfectant, thereby reducing the concentration available for surface decontamination. Moreover, the surface to be disinfected has an unknown disinfectant demand such that even a wet applicator can only be expected to function properly over a limited area. Label directions for marketed environmental surface disinfectants normally do not account for this in claiming microbicidal activity nor do they give any clear guidance on how to apply the product and the optimal ratio between its volume and the surface area to be covered. The absence of such crucial details can seriously undermine the intended purpose of environmental surface disinfection and turn it into no more than a ritual.

With regards to wiping, there is also much talk these days on the benefits of using microfiber-based fabrics (MFBF) for decontaminating environmental surfaces.[39-48] Thus far, peer-reviewed literature on the topic is quite limited, and that too comes from wide variations in test protocols. This, together with inherent differences in MFBF themselves, makes meaningful comparisons virtually impossible. Nevertheless, it appears that MFBF of good quality, when used properly, do have the potential to remove surface contamination more efficiently and retain it better to reduce the risk of its spread during wiping. Their use may also require lower concentrations of disinfectants, thus cutting down on the loading of the environment with potentially harmful chemicals. Table 3 lists the relative advantages and limitations of MFBF as gathered from a variety of sources.

MFBF can also be chemically impregnated with receptors that can bind microbicides.[49,50] Such fabrics

Table 3. Advantages and limitations of microfiber-based fabrics for wiping hard, nonporous environmental surfaces

Advantages	Limitations
Light in weight (ergonomic) and highly flexible	Higher initial investment
Efficient pick-up and retention of contamination	Higher surface contact and resistance to gliding
Hypoallergenic; wrinkle resistant	Dry mopping good only for pick up of dust
Can be lint free unless cut fibers are used	Less efficient when fully saturated
Can be washed and reused 500 times or more	Washing with other fabrics may trap lint
Lower disinfectant use	No fabric softeners and quaternary ammonium compounds (clog up pores)
Require less water for use	No bleach on certain types (eg, polyamide)

require wetting only in water to exert a chemicophysical action during wiping of surfaces. Systematic testing is needed to assess properly whether their microbicide-binding capacity confers on them any advantages over regular MFBF when used on surfaces common in health care settings.

SELF-SANITIZING SURFACES

For claims of self-sanitization, a disinfectant can be chemically bound[50,51] to an environmental surface or it can be made from material doped with a disinfectant.[52] Also, titanium dioxide-containing coatings can release microbicidal ions upon exposure to ultraviolet light[53] or natural sunlight[50]; this is essentially an oxidizing process. More recently, the US Environmental Protection Agency has granted copper and several of its alloys the first ever registration as inherently antimicrobial hard surfaces.[54,55]

The development and manufacture of such ''self-sanitizing'' or ''self-disinfecting'' surfaces and those with residual antimicrobial activity are big business these days, whereas the true benefits of applying such technologies to prevent the spread of pathogens via environmental surfaces in health care settings remain insufficiently documented. In case they prove beneficial in the short-term, what are the potential risks in their widespread and long-term use? The following issues need special attention in this context:

1. Tests currently available for self-sanitizing environmental surfaces (SSES) cannot properly assess their activity against pathogens in dust or dry particulates. In the absence of a sufficient level of moisture, contamination in a dried state may remain unaffected except for natural biologic decay.
2. Even though viruses are among the most prominent nosocomial pathogens,[13,56] they are often not included in testing SSES, possibly because the common actives in SSES cannot readily inactivate viruses, especially the nonenveloped ones.
3. Large quantities of relatively stable microbicidal chemicals would be needed to meet the demand for SSES in health care and other facilities. Even minimal leaching could load the environment with substantial amounts of such chemicals on a sustained basis.
4. It is not difficult to conceive that a time-related decay in the active chemical could easily bring it to levels sublethal for nosocomial pathogens; this may select for microbicide-resistant strains and also possibly contribute to cross-resistance. As an example, exposure of microorganisms to metals often elicits resistance mechanisms that tend to be linked to antibiotic resistance,[57,58] and surfaces such as copper can become readily oxidized so that copper ions are not readily released.
5. The use of copper and its alloys as materials for environmental surfaces in health care settings must also be properly assessed in view of the increasing use of oxidizers for disinfection of such surfaces. US Environmental Protection Agency's registration of such surfaces also acknowledges that copper alloys require approximately 2 hours for ~3-$\log_{10}$ reduction in vegetative bacterial pathogens.

GOVERNMENT REGISTRATION OF DISINFECTANTS

Not unlike other regulations, the testing requirements for government registration of disinfectants often lag behind the changing profile of nosocomial pathogens and advances in disinfectant test methodologies. For instance, dozens of government-registered environmental surface disinfectants in North America claimed activity against *Clostridium difficile* using the vegetative form of this anaerobic spore former. Only recently has corrective action been taken through a voluntary recall of such label claims and testing against the spores now made mandatory.[59] Other concerns with label claims of environmental surface disinfectants have recently been highlighted elsewhere.[60] The reality is that no matter what strides are made in formulating better and safer disinfectants and in methods to assess their microbicidal activities, newer, and perhaps better, products cannot be brought to the field unless they are approved for sale by the concerned regulatory agency. Although this is surely in the interest of public safety, the generally slow and restrictive process of review of such submissions tends to stifle innovation. The wide variations in national and regional

requirements for testing and registration of disinfectants, with the attendant investments in time and funds, are also a serious deterrent for innovation.

''No touch'' technologies based on ultraviolet irradiation[61] and aerial release of chemicals[62,63] to disinfect environmental surfaces are also rapidly coming on stream. Although they offer certain advantages over the direct application of chemicals for surface decontamination, standardized and widely accepted methods to assess the microbicidal potential of such technologies remain unavailable nor are regulations in place to approve them for sale. This is yet another area in urgent need of attention.

CONCLUDING REMARKS

Many traditionally used products and practices for decontaminating environmental surfaces in health care settings are now under scrutiny for their effectiveness and relevance with the changing profile of nosocomial pathogens on the one hand and human[64] and environmental safety on the other. For instance, there is now irrefutable evidence showing that the routine cleaning and disinfection of environmental surfaces in many hospitals are quite frequently totally inadequate, with much contamination left behind.[9] In addition, there is often a disparity between label directions for disinfectants and how they are actually used in the field.

All this awareness together is generating a strong momentum for change in regulations at all levels[65]—a harbinger for substantial improvements soon to come. It would thus be premature to let up on this pressure for change. First and foremost, regulators must find ways of updating the requirements for product registration in step with the fast-changing knowledge base and technologic innovations. Manufacturers must devote the resources to develop products to better address the emerging awareness of environmental and workplace safety as well as a more generic approach to disinfection rather than the current tendency to focus on the ''bug-de-jour.'' Infection prevention should have a higher profile, and its practitioners must recognize that they have a very crucial role to play as they are often on the front lines and have much to gain personally and professionally from better and safer products and procedures for countering nosocomial pathogens. Manufacturers and regulators alike could benefit immensely from positive and negative feedback provided by end-users, who also must refrain from asking for irrelevant and scientifically invalid label claims.[16] Last, but not least, researchers must recognize that environmental control is an area worthy of their attention; they must also lobby granting agencies to assign it adequate research funding.

There is no denying the benefits of disseminating information. Sadly though, many targets of such information may not have the time, inclination, or acumen to separate the wheat from the chaff, while feeling the pressure to be in vogue. This obviously runs counter to a ''science-based'' approach many profess to follow. In other words, adopting something ''new'' would require much care to avoid expensive and potentially harmful mistakes. Besides, should we be seeking something ''new'' while not optimally using what exists already? The now well-documented issue of inadequate cleaning/decontamination of environmental surfaces in many health care settings is a highly relevant case in point.[9,34]

In the United States, nearly 60% of some 5000 registered antimicrobial products are sold to control pathogens in hospitals and other health care settings[66]; a major proportion of such marketed products is for use on environmental surfaces. In spite of this routine reliance, most materials managers and end-users remain insufficiently aware of the limitations and general safety of many of the products in current use.[16] An effective disinfection regime relies on selecting suitable products and using them diligently in well-designed protocols. Although disinfectants continue to be the backbone of infection control, and our reliance on them is increasing further in view of mounting antibiotic resistance and the on-going assault from emerging and reemerging infectious agents, we must not use them improperly or indiscriminately simply to acquire a false sense of security. They are not magic bullets and will not compensate for poor practice.

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