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Review

The role of 'no-touch' automated room disinfection systems in infection prevention and control

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SUMMARY

Background: Surface contamination in hospitals is involved in the transmission of pathogens in a proportion of healthcare-associated infections. Admission to a room previously occupied by a patient colonized or infected with certain nosocomial pathogens increases the risk of acquisition by subsequent occupants; thus, there is a need to improve terminal disinfection of these patient rooms. Conventional disinfection methods may be limited by reliance on the operator to ensure appropriate selection, formulation, distribution and contact time of the agent. These problems can be reduced by the use of 'no-touch' automated room disinfection (NTD) systems.
Aim: To summarize published data related to NTD systems.
Methods: Pubmed searches for relevant articles.
Findings: A number of NTD systems have emerged, which remove or reduce reliance on the operator to ensure distribution, contact time and process repeatability, and aim to improve the level of disinfection and thus mitigate the increased risk from the prior room occupant. Available NTD systems include hydrogen peroxide (H_2O_2) vapour systems, aerosolized hydrogen peroxide (aHP) and ultraviolet radiation. These systems have important differences in their active agent, delivery mechanism, efficacy, process time and ease of use. Typically, there is a trade-off between time and effectiveness among NTD systems. The choice of NTD system should be influenced by the intended application, the evidence base for effectiveness, practicalities of implementation and cost constraints.
Conclusion: NTD systems are gaining acceptance as a useful tool for infection prevention and control.

Introduction

Contaminated surfaces have been underestimated as a source from which nosocomial transmission can occur.[1–3] Recent studies show that admission to a room previously occupied by a patient with *Clostridium difficile*, vancomycin-resistant enterococci (VRE), meticillin-resistant *Staphylococcus aureus*

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(MRSA), *Acinetobacter baumannii* and *Pseudomonas aeruginosa* increases the risk of acquiring these pathogens for subsequent occupants of the same room by a factor of two or more.[1,4–8] In these circumstances, current terminal cleaning and disinfection following the discharge of patients with these pathogens is inadequate and needs to be improved. The emergence of the 027/NAP1 epidemic strain of *C. difficile* and potentially untreatable multidrug-resistant Gram-negative bacteria that can also survive on surfaces is a further reason to improve environmental decontamination.[9,10]

Effective cleaning and disinfection using conventional methods relies on a human operator to correctly select and formulate an appropriate agent and distribute the agent to all target surfaces for the necessary contact time. Improvement of these conventional methods depends on modification of human behaviour, which is often difficult. The use of novel 'no-touch' automated room disinfection (NTD) systems provides an alternative approach, which removes or reduces reliance on the operator.[11–14] Automated systems have been adopted widely in other areas of healthcare to remove human error. Examples include robotic surgery and many aspects of critical care such as ventilators. Indeed, commenting on the future of infection control in the late 1990s, Dr Robert Weinstein wrote: 'Given the choice of improving technology or improving human behavior, technology is the better choice.[15]

Despite the relatively recent attention, the concept of NTD is not new. A paper was published in 1901 advising on how to disinfect a 'sick-room' through gaseous formaldehyde.[16] In the 1960s, formaldehyde was replaced by aerosolized chemicals such as quaternary ammonium compounds and phenolics due to concerns over toxicity.[17–19] However, advice from the US Centers for Disease Control and Prevention (CDC) since the 1970s is that disinfectant fogging should not be performed routinely in patient-care areas.[19,20] The emergence of several new NTD systems based on either H_2O_2 or ultraviolet (UV) radiation and the increasing recognition of the importance of environmental contamination in transmission suggests that this recommendation should be re-evaluated.[11]

This review presents evidence for the need to improve or augment conventional cleaning and disinfection; considers the targets for hospital disinfection and when use of an NTD system may be appropriate; summarizes and compares evidence relating to the various NTD systems; and discusses the role of regulators and professional societies in guiding evidence-based adoption.

What level of surface contamination is a risk for transmission?

The relationship between the level of residual surface contamination after disinfection and the risk of transmission has not been studied in detail. It depends on various factors, including the characteristics of the organism involved, patient susceptibility and staff compliance with infection control policies (for example hand hygiene following contact with environmental surfaces).[21–23] The fact that subsequent occupants of a room vacated by a previously colonized or infected patient are at an increased risk of infection indicates that conventional terminal disinfection does not reduce contamination sufficiently to prevent all transmission in these cases.[1,4,6–8] There is some evidence that the extent to which transmission is interrupted is proportional to the level of surface contamination. For example, Lawley *et al.* used an *in vitro* mouse model to show that the degree to which transmission of *C. difficile* was blocked correlated with the $\log_{10}$ reduction of the various disinfectants tested.[24]

The degree of shedding and the infective dose can be used to guide the appropriate target for hospital cleaning and disinfection. Certain pathogens such as *C. difficile* and norovirus can be shed into the environment in high numbers and have a low infectious dose.[1,25,26] For example, stool concentrations of norovirus can reach $>1 \times 10^{12}$ particles per gram and up to 10^5 virus norovirus particles per 30 cm^2 have been identified on hospital surfaces, whereas the infectious dose is 1–100 particles.[1,26,27] Therefore, the presence of a pathogen on a surface at any concentration may be a risk for transmission. This is reflected in proposed guidelines for microbiological hygiene standards and recent discussion surrounding the intended target for hospital disinfection.[28–30]

However, in practice, a risk-based approach must be used when setting a target for an acceptable level of residual contamination, balancing patient safety with practicality and cost, as is the case when selecting liquid disinfectants. More stringent targets should be set when the risk and/or consequences of infection are high, for example, for virulent, resistant and/or highly infectious pathogens, especially in high-risk settings with immunocompromised patients; a lower standard may be acceptable in lower-risk settings.[28–30]

Limitations of conventional cleaning and disinfection

Conventional cleaning and disinfection is performed by a human operator with liquid detergents or disinfectants. Microbiological studies indicate that conventional cleaning and disinfection without programmes of targeted improvement rarely eradicate pathogens from surfaces.[31–34] Problems associated with both 'product' and 'procedure' contribute to this (Box 1), in particular, the reliance on the operator to repeatedly ensure adequate selection, formulation, distribution and contact time of the agent. For example, a large assessment of conventional cleaning in 36 acute hospitals using fluorescent markers revealed that less than 50% of high-risk objects in hospital rooms were cleaned at patient discharge.[35]

Modifying human behaviour is difficult but several different approaches can be taken, including routine microbiological analysis of surface hygiene, the use of fluorescent markers or ATP assays to assess the thoroughness of cleaning, feedback of cleaning performance and educational campaigns.[5,11,28,35–37]

Monitoring and feedback can improve the frequency of surfaces that are cleaned and reduce the level of environmental contamination and there is some evidence that improving the efficacy of conventional cleaning/disinfection can reduce the acquisition of pathogens.[5,35,38,39,40–42] However, no studies have evaluated the sustainability of such systematic improvements. Indeed, recent evidence indicates that altering the location of fluorescent dye spots reduced the proportion of objects that were cleaned from 90% to approximately 60%.[11]

In situations where the elimination of pathogens is required, even systematic improvement of conventional cleaning and disinfection may not be sufficient. Multiple rounds of disinfection with sodium hypochlorite (bleach) taking many hours, risking damage to materials and presenting health risks for