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Consensus Paper

The role of surface disinfection in infection prevention

Die Rolle der Flächendesinfektion in der Infektionsprävention

Abstract

Background: The Rudolf Schuelke Foundation addresses topics related to hygiene, infection prevention and public health. In this context a panel of scientists from various European countries discussed "The Role of Surface Disinfection in Infection Prevention". The most important findings and conclusions of this meeting are summarised in the present consensus paper.
Aim: Although the relevance of surface disinfection is increasingly being accepted, there are still a number of issues which remain controversial. In particular, the following topics were addressed: Transferral of microbes from surface to patients as a cause of infection, requirements for surface disinfectants, biocidal resistance and toxicity, future challenges.
Methods and findings: After discussion and review of current scientific literature the authors agreed that contaminated surfaces contribute to the transmission of pathogens and may thus pose an infection hazard. Targeted surface disinfection based on a risk profile is seen as an indispensable constituent in a multibarrier approach of universal infection control precautions. Resistance and cross-resistance depend on the disinfectant agent as well as on the microbial species. Prudent implementation of surface disinfection regimens tested to be effective can prevent or minimize adverse effects.
Conclusions: Disinfection must be viewed as a holistic process. There is a need for defining standard principles for cleaning and disinfection, for ensuring compliance with these principles by measures such as written standard operating procedures, adequate training and suitable audit systems. Also, test procedures must be set up in order to demonstrate the efficacy of disinfectants including new application methods such as pre-soaked wipes for surface disinfection.

Keywords: hygiene, infection prevention, surface disinfection, biocide, resistance, cross-resistance

Zusammenfassung

Hintergrund: Die Rudolf-Schülke-Stiftung unterstützt die Forschung und Entwicklung von Strategien zur Hygiene, Infektionsprävention und Öffentlichen Gesundheit. In diesem Rahmen diskutierten Fachleute aus mehreren europäischen Staaten im Rahmen eines Arbeitsgesprächs den „Stellenwert der Flächendesinfektion in der Infektionsprävention". Die wichtigsten Ergebnisse und Schlussfolgerungen aus diesem Arbeitsgespräch sind im folgenden Konsensuspapier zusammengefasst.
Zielsetzung: Wenngleich die Bedeutung der Flächendesinfektion in den letzten Jahren gestiegen ist, gibt es noch eine Reihe von Themen, die kontrovers diskutiert werden. Im Einzelnen sind dies: die Übertragung von Mikroorganismen von der Fläche auf Patienten als Infektionsursache, Anforderungen an Flächendesinfektionsmittel, Resistenz und Toxizität von Bioziden, zukünftige Strategien.
Methode und Ergebnisse: Nach Diskussion und Sichtung der aktuellen wissenschaftlichen Literatur steht für die Autoren zweifelsfrei fest, dass pathogene Mikroorganismen über kontaminierte Oberflächen übertragen

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werden und Flächen somit ein Infektionsrisiko darstellen können. Gezielte Flächendesinfektion auf der Grundlage eines Risikoprofils ist als ein fester Bestandteil eines Multibarriereansatzes der allgemein anzuwendenden Schutzmaßnahmen zur Infektionsprävention anzusehen. Resistenzen und Kreuzresistenzen hängen sowohl vom einzelnen Desinfektionswirkstoff als auch vom jeweiligen Mikroorganismus ab. Darüber hinaus kann die sachgerechte Umsetzung von geprüften Maßnahmen zur Flächendesinfektion negative Auswirkungen verhindern oder minimieren.

Schlussfolgerungen: Die Desinfektion muss als Prozess betrachtet werden. Es sollten Standards für die Reinigung und Desinfektion erarbeitet werden und die sachgerechte Umsetzung dieser Maßnahmen durch schriftlich fixierte Standardarbeitsanweisungen, fundierte Aus-, Fort- und Weiterbildung und geeignete Auditsysteme sichergestellt werden. Zusätzlich müssen Testverfahren zur Überprüfung der Wirksamkeit von Desinfektionsmitteln einschließlich der Anwendung in Tuchspendersystemen im Vortränksystem entwickelt werden.

Schlüsselwörter: Hygiene, Infektionsprävention, Flächendesinfektion, Biozid, Resistenz, Kreuzresistenz

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Introduction

The Rudolf Schuelke Foundation addresses topics related to hygiene, infection prevention and public health. Every two years, the Foundation organises a symposium inviting a panel of scientists from various European countries to discuss a topic of current concern and special relevance for the field of hygiene. For the 2011 symposium, the Schuelke Foundation decided to assess "The Role of Surface Disinfection in Infection Prevention". The most important findings and conclusions of this meeting are summarised in the present consensus paper.

Background and objectives

The central importance of hand hygiene (hand disinfection) in the control of infections has been recognised since the time of Ignaz Semmelweiss, Florence Nightingale and Robert Koch. The insights gained from their scientific and practical works are still applicable today [1].

In contrast to hand hygiene, the relevance of surface disinfection or environmental disinfection has remained controversial. However, the view that environmental disinfection is important has recently begun to gain ground. Surface disinfection has been included in a number of recent national and international infection control policies and recommendations. One example is the guideline on *Hygiene Requirements on Surface Cleaning and Disinfection* which was published by the Commission for Hospital Hygiene (KRINKO) of the German Federal Robert Koch Institute (RKI) in 2004 [2]. (This Guideline was translated into English on behalf and responsibility of the German Society of Hospital Hygiene: http://www.dgkh.de/Nutzerdaten/File/empfehlungen/2010_rki_cleaning.pdf.)

In the same year, William Rutala and David Weber published their well-known paper "*Benefits of Surface Disinfection*" in the American Journal of Infection Control, concluding that "*it is reasonable to use hospital disinfectants on non-critical patient care surfaces, [including] patient equipment surfaces and housekeeping surfaces*" [3].

This increasing emphasis on the use of disinfectants for environmental decontamination is, to a certain extent, the consequence of a worldwide increase in the occurrence of microorganisms multi-resistant to antimicrobials and associated with high rates of nosocomial infections [4]. In addition, numerous scientific studies have furnished evidence for the transfer of microorganisms between surfaces and patients [5].

Although the relevance of surface disinfection is increasingly accepted, there are still a number of issues which remain unresolved. In particular, the following topics and questions need to be addressed:

1. What is the evidence that microbes are transferred from surfaces to patients and then cause (nosocomial) infection?
2. Which requirements have to be fulfilled by surface disinfectants?
3. What do we know about biocidal resistance in microorganisms and toxicity to humans and/or the environment?
4. Which guidelines, recommendations and regulations exist and how can they be made more effective?
5. Which future aspects and challenges have to be taken into consideration?

Evidence of the role of surfaces in the transmission of pathogenic microorganisms causing healthcare-acquired infections

In recent years, scientific evidence has accumulated which has confirmed the following concepts [5], [6]:

1. Bacteria, bacterial spores and viruses are shed from infected and/or colonized patients or staff into the hospital environment, especially into areas in the vicinity of patients and surfaces frequently touched by staff hands (termed "high-touch surfaces"). The wide variation in the reported frequency of contamination may be the result of different sampling and culturing methods, different rates of contamination during outbreaks, and differences in cleaning and disinfection practices. Respiratory tract infections and diarrhoea have a particularly high risk of widespread contamination. Compared with the large number of publications on methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE) and *Clostridium difficile*, there are relatively few studies on environmental contamination by Gram-negative bacteria and Norovirus.
2. Some bacterial species, including *C. difficile* spores, VRE, MRSA and *Acinetobacter* species, can survive for 4–5 months or more on dry surfaces, and norovirus can survive for up to one week [6].
3. The levels of surface contamination by microorganisms in hospitals are low in comparison to the concentrations on patient skin or in stools. However, there is a risk of transmission even at low concentrations. Hayden et al. showed that touching the environment contaminated with relatively low pathogen concentrations in a room occupied by a patient colonized by VRE is associated with approximately the same risk of VRE acquisition on hands as touching an affected patient directly [7]. Other in-vitro investigations on the transfer from surfaces to hands and vice versa corroborate these findings.
4. The risk of transfer is also affected by the infectious dose, which, for many nosocomial pathogens is low. For example, the infectious dose for norovirus is thought to be as low as one virus particle. Therefore, the presence of pathogens on surfaces, even at low concentrations, always carries the risk of transmission.
5. Good evidence of the importance of environmental transmission is provided by a number of studies showing an increased risk of infection in patients admitted to side rooms previously occupied by other infected cases. This has been shown for *C. difficile* [8], VRE and MRSA [9]. Environmental norovirus contamination has been repeatedly found to be correlated with continuing outbreaks, although the significance of this pathway has not been fully established.
6. The importance of surface contamination is also shown by the reduction in the rate of healthcare-associated infections when effective measures of environmental hygiene are implemented [10], [11], [12]. A recent observational study showed a significant reduction in *C. difficile* infection rates following the introduction of sporicidal wipes in an environmental cleaning regimen in an acute London trust [13]. However, not all studies have shown a direct link between surface disinfection and reduction in infection rates, probably because of the complex interactions and transmission routes in actual clinical practice.

More research is required to establish the true *extent* to which contaminated surfaces contribute to the transmission and to gain a better insight in the role of surface contamination in community and non-acute settings.

Surface disinfection as part of a multi-barrier approach

These findings support the importance of environmental contamination in healthcare settings. Nevertheless, it has been found that compliance with hand hygiene is significantly less after contact with the environment than with the patient [14]. This underlines the need to perform proper surface decontamination procedures within a multi-barrier approach (a "bundle strategy") to reduce and control pathogen transmission. This strategy should be implemented despite the existence of unresolved questions about the risks of environmental contamination. *"Absence of definite evidence for a health hazard is not equivalent to evidence of absence of risk. If circumstantial evidence points to a putative health hazard, appropriate prudent action is legitimate policy for consumer protection."* (modified from Mossel et al. [15]).

Within a multi-barrier approach, environmental disinfection policies should be based on risk assessments for different surfaces, with specific guidelines for different cleaning and disinfection measures. Education and training in cleaning procedures is also important and has been shown to improve both cleaning performance and infection rates [11]. Recommendations should be based on objective assessment of the various methods of decontamination, such as cleaning with standard cleaning agents and water, disinfection with different biocidal agents and the use of hydrogen peroxide vapour for terminal disinfection [16]. Other issues to be addressed include the safety and toxicology of the agents used, the potential development of biocidal resistance and the design, ease of cleaning and material properties of the complex surfaces in the hospital environment, including furniture.

The discussion of the symposium focused on requirements for liquid and vapour surface disinfection to reduce the survival and spread of nosocomial pathogens, including final (terminal) disinfection of rooms or areas previously occupied by infected or colonized patients. Surface

disinfection is defined according to prEN 14885 (draft 2012) *Chemical disinfectants and antiseptics – Application of European Standards for chemical disinfectants and antiseptics*, as chemical disinfection of a solid surface, excluding those of certain medical and veterinary instruments, by the application of a product with or without mechanical action. Application methods include circulation, dipping, flooding, immersion, spraying, fogging, wiping etc. [17]

The purpose of routine or targeted disinfection of inanimate surfaces is the killing or irreversible inactivation of pathogens to an extent which prevents subsequent infection transmission. Disinfection may be required in the following situations:

1. "high-touch" (i.e. frequently touched) surfaces near patients
2. surfaces where contamination is assumed
3. surfaces with visible contamination (blood, pus, excrements)
4. terminal disinfection in rooms or areas where infected or colonized patients were treated or nursed, or in outbreak situations.

Efficacy testing for surface disinfectants

General aspects of the interaction between biocides and microorganisms

General considerations of the efficacy of surface disinfectants include the mechanisms of action of the active substance and its interaction with the target organism. Many disinfectants contain multiple active substances. Inactivation of microorganisms proceeds from reversible processes such as the disruption of transmembrane proton motive force, to irreversible changes, such as lysis of the cell [18].

The effectiveness of a disinfectant depends on a number of factors: those inherent to the product, those inherent to the application, and those inherent to the microorganism. Product factors include concentration, formulation, water solubility and pH. For example, the concentration exponent, describing the relationship between dilution and activity of a biocide, must be considered, as well as the bioavailability of the substance and its stability. Application factors include the type of surface, the type of (organic) soil, the temperature and contact time as well as humidity and the mode of application (with or without mechanical action) [19].

Efficacy testing of disinfectants in Europe

When establishing a disinfection regimen, the efficacy of the disinfectant against the targeted spectrum of microorganisms must first be considered. Efficacy testing of disinfectants was introduced by Robert Koch in 1881: "*I just want to remind about that what is already done in the field of disinfection. Especially for this field in former times a real experimental background was missing.....and a lot of money was thrown away for useless disinfection. But now we have very secure characteristics (data) in our hands.....to test disinfecting substances concerning their efficacy..... so that the now used disinfecting substances, as far as they have passed our tests, really fulfil their purpose*" [20]. Nowadays, disinfectant testing is conducted at an international level by the Organisation for Economic Co-operation and Development (OECD), at a European level by the *Centre Européen de Normalisation* (CEN) and at a national level by various professional societies and institutions.

In 1970, the Rudolf Schuelke Stiftung founded the International Colloquium for the Evaluation of Disinfectants in Europe. Members of this group included experts from Austria, Belgium, West Germany, the Netherlands, Sweden, Switzerland and the United Kingdom. The aim was to bring together and harmonise the various national activities on efficacy testing.

Since 1989, methods for efficacy testing of disinfectants in Europe have been developed by the Technical Committee 216 (TC 216) "*Chemical disinfectants and antiseptics*" of CEN. Working Group 1 (WG 1) of TC 216 focuses on human medicine and has been allocated to the Deutsches Institut für Normung (DIN) in Berlin. The main objective of TC 216 is to develop standardised test methods in three phases.

1. Phase 1 tests are **quantitative suspension tests** to establish that active substances or products under development have bactericidal, fungicidal or sporicidal activity without regard to specific areas of application. Phase 1 tests cannot be used for any product claim.
2. Phase 2 comprises two steps. *Phase 2, step 1 tests* are **quantitative suspension tests** to establish that a product has bactericidal, fungicidal, yeasticidal, mycobactericidal, tuberculocidal, sporicidal or virucidal activity under simulated practical conditions appropriate to its intended use. *Phase 2, step 2 tests* are **quantitative laboratory tests** to establish that a product has bactericidal, fungicidal, yeasticidal, mycobactericidal, tuberculocidal, sporicidal or virucidal activity when applied to a surface or skin **under simulated practical conditions** (surface, instrument, handwash and handrub tests).
3. Phase 3 tests are **field tests under practical conditions**. Applicable methodology for this type of test is not yet available but may be developed in the future.

WG 1 has formed several special Task Groups, including a Surface Task Group, a Sporicidal Task Group and a Virucidal Task Group. Table 1 gives an overview on the present state of standards produced by WG 1 with respect to surface disinfection *in phase 2*.

In *Phase 2/step 1*, the test product has to reduce the test organisms by at least 5 logs (or 4 logs for yeasticidal,

Table 1: Overview on the present state of standards produced by WG 1 with respect to surface disinfection procedures in phase 2

Claims for acitivity of surface disinfectants							
Test phase 2	Bactericidal	Fungicidal	Yeasticidal	Mycobactericidal	Tuberculocidal	Virucidal	Sporicidal
Step 1	prEN 13727 rev	prEN 13624 rev	prEN 13624	EN 14348	EN 14348	EN 14476rev	Work item 00216068 submitted Jun 2011
Step 2 Clean and dirty conditions	Work item 00216049 submitted Nov 2011	–	Work item 00216049 submitted Nov 2011	–	–	Work item 00216070 submitted Nov 2011	Proposal Gemein/ Gebel

fungicidal, mycobactericidal and virucidal activity) under clean and dirty conditions at the specified exposure times. *Phase 2/step 2* requirements are under discussion. Test organisms must be reduced by 5 logs for bacteria or 4 logs for yeasticidal, fungicidal, mycobactericidal and virucidal activity under conditions simulating practical use [17], [21], [22]. The work item "*Quantitative test method for the evaluation of bactericidal activity on non-porous surfaces with mechanical action employing wipes or mops in the medical area – Test method and requirements (Phase 2, step 2)*" proposes the 4-Field-Test [21]. This test incorporates a wiping procedure back and forth across four test areas, simulating in-use conditions, and was submitted in November 2011 along with the work item on virucidal efficacy testing. Both tests will be discussed during 2012 and hopefully accepted in 2013. A first proposal referring to room disinfection was published by Koburger et al. [16]

Tests for *sporicidal* activity were proposed by S. Gemein and J. Gebel in June 2011 (Table 1). For Phase 2/step 2 tests, the modified 4-Field-Test was incorporated in the proposal. In contrast to present OECD methods, which are performed without mechanical action, this test employs a wiping mechanical action in addition to specifying the volume of disinfectant solution to be applied to the surface [23]. Since wiping may be associated with the spread of microorganisms, it is a requirement that there is no dissemination of potentially pathogenic microorganisms during a cleaning and disinfection procedure. Also, because variations in disinfection efficacy occur with differences in the composition of both wipes and surfaces, the entire disinfection process must be validated.

Efficacy testing at a national level

The German Disinfectants Commission of the Association of Applied Hygiene (VAH) is an independent expert panel founded in 1959, initially as a Commission of the German Society for Hygiene and Microbiology (DGHM). Its tasks include the development of guidelines and standards for efficacy tests, and all valid European standards are integrated in the DGHM/VAH test methods. VAH efficacy tests comprise phase 2/step 2 tests for surface disinfectants and other applications. The VAH Disinfectants Commission compiles a list of effective disinfectants tested according to the DGHM Standard Methods [24], [25]. This list provides the end-user with a choice of reliably effective disinfectants for routine applications tested under conditions simulating practical use.

Test guidelines also exist in a number of other European countries, among them Austria and France. VAH is presently exploring the possibility of compiling a European-wide list of tested disinfectants.

Sustained activity

The 4-Field-Test mentioned above also permits an assessment of sustained activity of various disinfectant ingredients. The residual effect is greatest for a combination of quaternary ammonium compounds and alkylamine, less for aldehydes and least for alcohols.

Disinfection protocols should take into consideration where surface disinfectants with a sustained effect are needed and what are the risks of their application. This is especially important when low concentrations of disinfectant are applied, because there is evidence that low quantities of disinfectant may trigger the development of resistance [26].

New and emerging applications of surface disinfectants

Use of pre-soaked wipes

The use of pre-soaked disinfectant wipes has found broad acceptance in hospitals. However, the combination of quaternary ammonium compounds (QACS) with an inappropriate type of fabric will more or less abolish its antimicrobial activity. In this case, the intended disinfection process may only be a cleaning process, putting patients at unnecessary risk [27]. Another problem is the containers in which the wipes are stored for up to 28 days in accordance with the manufacturer's recommendations.

If the containers are not properly cleaned and disinfected, they may become a reservoir for pathogens like *P. aeruginosa,* which may develop tolerance to the disinfectant being used [28], [29].

Because of these problems, the Royal College of Nursing (London) has published detailed recommendations on the proper selection and use of disinfectant wipes [30]. In their introduction the authors point out: *"Pre-prepared wipes are increasingly being used in clinical situations for the cleaning or disinfection of low risk equipment and the near-patient environment.....Despite their growing popularity, however, there is a poor level of evidence to support the efficacy of disinfectant wipes in real life use. This is particularly important when wipes are used to support a reduction in the transmission of micro-organisms via the environment, including spores such as Clostridium difficile ("C. diff"). If wipe products prove ineffective, there is a potential risk to the provision of a safe environment. There is also susceptibility for wipes to dry out and lose efficacy during use, or as a result of storage once a tub of wipes has been opened. Regulatory and other standards require that decontamination – whether via wipes or any other means – is achieved as a result of an adequate and informed process. If wipes are to accomplish their intended purpose, it is essential to consider whether wipes do contribute to an effective intervention and to ensure the correct selection and management of wipes*." Furthermore the authors point out: "*There are currently no accepted standards to support the selection and purchase of disinfectant wipes in health care. This is due in part to wipes being a relatively new concept and the absence of a current consensus on what such a test might include. In practice this means that the disparate claims by manufacturers need to be evaluated carefully*."

Terminal disinfection

Terminal disinfection is performed in areas or rooms previously used for nursing or treating patients infected and/or colonised with pathogens. This disinfection aims to ensure that the room/area can be re-used safely for other patients without posing an infectious hazard. Terminal disinfection is applied to all potentially contaminated surfaces and objects. Formerly, rooms were disinfected with formaldehyde vapour but this has been abandoned because of toxicity. However, encouraging results have recently been obtained for a wide range of pathogens by gassing with the much safer hydrogen peroxide vapour/aerosolized hydrogen peroxide [31], [32], [33].

Toxicity and risks of resistance development

Toxicity

All biocides have some toxicological risks to human health and/or the environment. Therefore, disinfection procedures must include a risk assessment of potential toxicological hazards. These hazards mainly depend on the active ingredient used.

- Alcohol-based compounds are not known to exhibit adverse effects [34]. They are suitable for disinfection of small surface areas.
- The oxidants formic acid and sodium hypochlorite are used for large surfaces and also do not have significant toxic side effects.
- Phenolic compounds vary considerably in their properties, depending on their chemical structure. For example, diphenylic compounds are better tolerated than halogen phenols and alkyl derivatives of phenols. In general, however, phenolic are regarded as slightly toxic. They possess a low sensitizing risk, but they are somewhat mutagenic and they have a high aquatic toxicity, especially triclosan [35]. Inhalation of phenolic vapours can lead to irritation of the airways and eyes. Long-term exposure may cause reproductive toxicity. Their antimicrobial spectrum is limited and they are not now commonly used for surface disinfection.
- Aldehydes, such as formaldehyde, glutaraldehyde and glyoxal, are classified as highly toxic, and have, depending on the compound, sensitizing, carcinogenic, mutagenic and neurotoxic effects. Consequently, they should not be used for routine surface disinfection and require specific indications [36].
- Quaternary ammonium compounds (QACs) are often regarded as substances without toxic risks. This has led to their widespread use in households as well as healthcare institutions, despite their rather limited spectrum of activity. However, recent research has shown that benzalkonium chloride, a prototype QACS, may induce strong inflammatory irritation, including asthma and eczema, by contact as well as by inhalation. Air contamination with QACs may occur as a result of QAC particles being released from surfaces, followed by accumulation in dust [37]. Thus, QACs may exhibit a higher allergenic potential than previously assumed, although there is no evidence of mutagenicity, teratogenicity or carcinogenicity.

Biocides and antimicrobial resistance

The development of resistance and multi-resistance to antimicrobials of a growing number of microorganisms and the resulting treatment failure has prompted the development of surveillance networks at local, regional, national and international levels. In 2008, the Council of the European Union (EU) adopted 23 Conclusions on Antimicrobial Resistance (AMR), stressing the importance of improving surveillance and control of antimicrobial resistance within the EU [4].

There are a number of questions under discussion concerning the use of biocides and antimicrobial resistance, including:

1. Can microorganisms become resistant to biocides?
2. Are there correlations between biocide usage and resistance to antibiotics?
3. What other factors contribute to a reduced susceptibility of microorganisms to biocides?

The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) published their "*Assessment of the Antibiotic Resistance Effects of Biocides*" [26] and subsequently their "Research strategy to address the knowledge gaps on the antimicrobial resistance effects of biocides" in 2009 [38]. SCENIHR identified "*serious gaps in knowledge*", including a lack of quantitative data on biocide use, including data on concentrations and environmental conditions (temperature, organic load, contact time). In these reports, surface disinfection refers to "*chemical disinfection of a solid surface, excluding those of certain medical and veterinary instruments by the application of a product (CEN/TC 216)*".

There is an urgent need to establish accepted standard protocols and tools for the evaluation of antimicrobial resistance induced or selected by a biocide. Such protocols should include repeated biocide exposure at sublethal (including residual) concentrations.

Resistance to biocides is assumed to be mainly a result of the ability of a bacterium to decrease intracellular biocide concentrations below the harmful threshold [26]. Mechanisms such as changes in cell envelope, changes in permeability, efflux and degradation can be the reasons for such a decrease. They can be intrinsic or acquired.

Some experimental data show a possible relationship between biocide exposure and antibiotic resistance, especially for triclosan, silver, chlorhexidine and quaternary ammonium compounds [39], [40], [41], [42]. One important form of linkage is (acquired) disinfectant cross-resistance with antibiotics, i.e. the existence of resistance mechanisms which are directed against both biocides and one or more therapeutic antibiotics, such as efflux [43].

The transfer and co-transfer of genetic determinants encoding for resistance to antimicrobial drugs following biocide exposure is also of concern, but so far has been poorly evaluated [42]. A recent prospective cohort study by Buffet-Bataillon et al. [44] demonstrated an epidemiological relationship between higher MIC values of alkyldimethylbenzylammonium chloride in clinical *E. coli* isolates and simultaneous resistance to cotrimoxazole.

In 2010, the Scientific Committee on Consumer Safety (SCCS) published a report identifying several risks associated with the use of triclosan, including the existence of mechanisms which can promote resistance and cross-resistance to biocides and antibiotics [45]. Genes conferring resistance to triclosan can be transferred to other bacteria, however, a decrease in susceptibility to triclosan is not always associated with a decrease in susceptibility to antibiotics [46]. However, the clinical relevance of these laboratory findings on triclosan have not yet been corroborated [47]. The recommended use concentrations of triclosan are much higher than the experimentally elevated MICs, except for those seen with *P. aeruginosa*. This underlines the importance of considering the spectrum of activity with different species when selecting a product.

There is laboratory evidence suggesting that biocides used at a sub-lethal concentration may trigger the expression of biocide resistance and/or select bacteria resistant to antibiotics [42], [48]. It is therefore crucial for a biocide to reach a lethal concentration rapidly.

Other factors contributing to decreased susceptibility to biocides and/or the selection of resistant microorganisms are biofilm-formation, the embedding of bacteria in amoeba, spore formation, and certain cell wall structures (as in mycobacteria). Recent publications describe the negative consequences of persistent biofilms on effective terminal cleaning of clinical surfaces [49], [50] underlining the need to closely monitor disinfection practices.

The selective pressure on resistant bacteria may further be enhanced by the cumulative exposure to biocides in the healthcare environments and biocides used in consumer products as preservatives.

In conclusion, current data suggest a possible linkage between usage of certain biocides and resistance to both biocides and antibiotics. However, there is considerable variation between bacterial species and individual biocides and antibiotics. Furthermore, the epidemiological relevance of the available data is unclear and a final statement on the resistance risks associated with biocide use cannot be made. Further research is needed to better understand the relationship between biocides and antimicrobial resistance.

Nevertheless, the present scientific data does not suggest that resistance problems will emerge, provided there is proper use of efficacious surface disinfectants [51]. Actions to reduce the potential impact of biocides on antimicrobial resistance include:

- Design and use biocidal products which rapidly reach lethal concentrations
- Odentify sublethal concentrations which may trigger resistance
- Avoid repeated, widespread use of biocides at sublethal concentrations
- Carefully assess the risk/benefit profile for triclosan, QACs and other substances suspected of triggering resistance
- Provide clear, intelligible instructions and training on the proper use of disinfectants
- Ise antimicrobial substances, including biocides, prudently. This implies the restricted, targeted use of disinfectants and consumer products containing biocidal agents in private homes
- Provide better surveillance and monitoring of the actual use of disinfectants
- Establish structured reporting of biocide resistances.

The Biocidal Product Directive

At a European level, the use and marketing of chemicals in disinfectants is regulated by the Directive 98/8/EC of the European Parliament and of the Council [52]. According to this Directive, a biocidal product must pose no risk to humans, animals or the environment under the conditions of use. Compliance with the Directive is a requirement for placing the product on the market. Surface disinfectants – unless used on medical devices – can be classified as *product type 2 in Main Group 1* (Disinfectants and general biocidal products, Private area and public health area disinfectants and other biocidal products). The active substances for this product type must be listed in Annex I (main list of active substances), Annex IA (active substances for low-risk biocidal products) or Annex IB (basic/commodity substances). Products which contain active substances not listed in these annexes must be removed from the market. Of about 760 initially identified active substances for all product types, 360 are still in the evaluation stage. It is expected that further active substances will be excluded from Annex I even though they have been used in disinfectants over a long period of time. As a consequence, a number of currently available biocidal formulations will disappear from the European market within the next ten years. However, implementation of the Directive varies amongst the individual member states.

Harmonised guidelines and recommendations

Several national guidelines and recommendations on environmental disinfection are available [2], [53]. In addition, WHO has published a number of interim best practice guidelines and technical notes on environmental disinfection [54]. However, controversial recommendations and ineffective or unsafe practices (e.g. the use of bleach in the presence of organic material, fumigation with formaldehyde) has led to a re-appraisal of existing WHO guidelines. The aim of a new guideline related to Infection Prevention and Control (IPC) Precautions in Health Care is to provide a reference standard to be adapted for local practice. It must also consider the needs of low-income countries.

The detailed national guideline "*Hygiene Requirements on the Cleaning and Disinfection of Surfaces*" issued by the German Hospital Hygiene and Infection Prevention Commission KRINKO in 2004 may serve as an example [2]. Amongst other issues, it defines risk areas (including high risk areas such as intensive care, operating theatre, stem cell wards) and the targeted spectrum of activity, addresses the correct dosage of disinfectants, training and supervision of cleaning staff, disinfection intervals, storage of cleaning and disinfection utensils and durability of furniture and equipment.

Guidelines and recommendations must also consider practical implementation. This may be achieved by keeping guidelines simple and easy to follow and also ascribing them the necessary legal status. Existing documents should be re-evaluated, current scientific findings included and basic principles agreed. The harmonised guidelines should then be made available to a wide audience across national borders.

Implementation and quality assurance of environmental disinfection

From the presentations and the discussion at this Rudolf Schuelke Foundation Symposium, the members identified an urgent need for immediate action on the practical implementation of environmental disinfection.

Focus on disinfection as a procedure

Disinfection must be viewed as a **holistic process**, taking into account aspects inherent to

- the product itself,
- the application of the product,
- the target microorganisms,
- disinfection efficacy and
- the methods of monitoring compliance.

Set up harmonised standard principles

Harmonise basic principles, standards and techniques for cleaning and disinfection of environmental surfaces. This should ideally be done by the ECDC for better acceptance in Europe and by WHO for better international acceptance. These standards should be based on risk assessments of contaminated surfaces and should include

- requirements for product efficacy,
- correct dosage,
- shelf-life,
- application techniques,
- toxicity and
- resistance potential.
- The special needs of low-income countries and outbreak scenarios in disaster areas should also be addressed.

Ensure compliance with standard principles

Standards for assessing compliance with guidelines should be established (conformity assessment). These standards can be compiled in the form of a list of compliance criteria, which should be an integral part of cleaning and disinfection protocols. If cleaning and disinfection services are outsourced, these compliance criteria should be part of a service-level agreement, which should include:

- adequate training and (continuing) education of both in-house and external staff,
- consultation with the infection control team,
- written Standard Operating Procedures,
- appropriate choice of disinfectant and other utensils needed for cleaning and disinfection,
- implementation of external and/or internal audits.

Specific reference must be made to the required qualification of cleaning personnel and the choice of adequate audit systems and monitoring techniques.

Define a core curriculum for cleaning personnel

A core curriculum should be adopted for the training and education of cleaning personnel in medical facilities, including the necessary qualifications of their trainers and supervisors. Currently, curricula for hospital cleaning specialists differ considerably in contents and length even within the same country, ranging from 4 week courses to a 2 year course with a diploma from a technical college (in France). High-quality teaching materials should be made available, tailored to the needs of the trainees. Training and education can include detailed on-site instruction by disinfectant manufacturers on the proper use of their individual products.

Evaluate and establish audit systems

Audit systems for monitoring the efficacy of cleaning and disinfection practices must also be evaluated. Examples of effective strategies involve the principles of "first consult, then supervise" adopted by the Public Health Authority in Frankfurt/Main. Public Health Authorities in Germany are obliged by law (IfSG 2011) to inspect medical facilities, including hospitals and doctors surgeries, assessing their compliance with hygiene regulations. In Frankfurt, emphasis is put on consulting the facility first rather than first pointing out failures [55], [56]. Another example is the "traffic light system" introduced in many hospitals in the UK. This system grades hospitals and health boards by the traffic light colours – red for a compliance level of less than 70%, amber for between 70% and 90% and green for above 90%. Audits in the UK can be carried out by domestic services managers or by independent teams, sometimes including members of the public. Generally, feedback about the compliance and efficacy of disinfection regimens leads to significant improvements in performance [57], [58].

Evaluate and establish monitoring techniques

Research gaps exist in objective methods for defining and measuring adequate cleanliness of various environmental surfaces. An expert panel should discuss and agree on indicators for existing monitoring techniques which are suitable for medical and public facilities (cf. *CDC Options for Evaluating Environmental Cleaning*) [59]. Available methods include fluorescent markers, adenosine triphosphate (ATP) bioluminescense to measure residual organic matter on surfaces, and microbiological tests such as swab cultures and Agar Slide Cultures, although the value of cultures is questioned and process controls are generally regarded as more useful.
Monitoring should include safe processing of surface disinfection utensils, especially mops.

Raise awareness

Healthcare personnel, hospital directors, patients, politicians and the public should be made more aware of the need to include appropriate environmental disinfection procedures within the infection control strategy and of the adverse consequences of failures in compliance or improper performance. These messages should also be communicated via the internet and in public media. A better understanding of the role of environmental disinfection will also encourage the funding of any additional costs involved in implementing a quality-assured environmental disinfection programme in medical facilities.

Share expertise

A continuing exchange of expertise between scientists, manufacturers, hospital directors, purchasing department, infection control personnel and end-user (cleaning staff and facility managers) should be established to improve the quality of environmental disinfection procedures.

Encourage competition

Competition between hospitals and medical care facilities, such as publishing audit results of infection control measures, can be useful for improving performance.

Use of household disinfectants

The use of disinfectants in the domestic environment requires specified indications. Generally, it is encouraged in situations where there is an increased risk of infection for household members and where additional safety is needed. The following indications may justify the use of surface disinfectants in private homes (also refer to the recommendations on home hygiene provided by the International Forum on Home Hygiene (IFH)):

- The presence of gastrointestinal infections, if immunosuppressed or susceptible persons (including newborns) are household members, provided the focus is on hand disinfection, supplemented by disinfection of risk areas in the bathroom and kitchen [60];
- If a family member has an infection caused by a highly contagious pathogen such as norovirus, tuberculosis or enteropathogenic *E. coli*. If Norovirus is involved, virucidal surface disinfection must be used after contamination with faeces or vomitus;

- If a patient discharged from hospital returns home with invasive medical devices or wound dressing still in situ [61];
- If preventative measures for re-colonization of MRSA carriers are implemented, which include hand disinfection in combination with the disinfection of relevant contact surfaces [60], [62].

Concluding remarks

There is now good evidence that contaminated dry surfaces contribute to the spread of nosocomial pathogens. It is undisputed that environmental disinfection is necessary in certain risk areas and in outbreak situations.
It is widely acknowledged that proper use of disinfectants contributes to the control of pathogens in outbreak situation as part of a bundle strategy.
There is an urgent need to harmonize test procedures in order to demonstrate the efficacy of disinfectants including new application methods such as pre-soaked wipes for surface disinfection.
Current understanding of toxicity and resistance mechanisms confirms that prudent implementation of surface disinfection regimens can prevent or minimize adverse effects.
There are many reports of insufficient and inadequate implementation of existing environmental cleaning and disinfection regimens. Therefore, future activities should focus on improving the quality of and the compliance with environmental disinfection procedures in accordance with a carefully designed set of standards.

Notes

Dedication

Dedicated to the memory of Yves Chartier (WHO) who participated in the conference and died in a tragic accident in January 2012.

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Competing interests

The authors declare that they have no competing interests.

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