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Review Article

Unlocking the Power of Effective Disinfection: Key Factors Revealed

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Abstract

The type of microorganisms are crucial, as some are more resistant than others, such as bacterial spores compared to vegetative bacteria. The presence of organic and inorganic matter can impede disinfection by protecting microbes or neutralizing disinfectants. Proper prior cleaning of surfaces can enhance disinfectant effectiveness by reducing microbial load. Disinfectants are antimicrobial chemicals that are applied to the surfaces of inanimate objects to kill germs that live on them. The effectiveness of germicides against microorganisms is contingent upon multiple factors, including those inherent to the organism and those arising from the chemical and physical surroundings.

The concentration and contact time of the disinfectant are also vital, with higher concentrations and longer contact times generally being more effective. Surface characteristics, such as porosity, impact how well a disinfectant works, with non-porous surfaces being easier to disinfect. Additionally, environmental factors like pH and temperature play significant roles, as certain disinfectants perform better under some specific conditions. By optimizing these factors, disinfection practices can be significantly improved, ensuring higher levels of cleanliness and safety. This chapter gives an insight about factors affecting efficacy of disinfection. It will also include some basic definitions, guidelines regarding disinfection and sterilization and a quick checklist to test the effectiveness of commonly used disinfectants.

Keywords: *Disinfection; Efficacy; Factors; Disinfectants; Sterilization*

Introduction

The existence of microbes is a well-established fact, dating back to the origin of the universe. Approximately 1 trillion microbes have been identified from the beginning of universe [1]. Lethal disease are caused by various microorganisms. It can range from simple flu to life threatening infections of HIV virus [2].

Different combating strategies with microbes were developed which can decrease the incidence of diseases caused by these germs. They can be antimicrobials, antivirals, antifungals, and antiprotozoals used *in vivo*, along with various disinfectants and modern sterilization techniques used *in vitro*.

Sterilization is the process of entirely removing and killing all microbial life, including spore and vegetative forms, and it can be done using a variety of physical and chemical techniques [3]. However disinfection is the process of completely removing all vegetative germs from inanimate things, with the exception of bacterial spores [3].

Disinfectant (dis'in-fek'tănt) is a substance which is capable of destroying pathogenic microorganism or inhibiting their growth activity [4]. Disinfection is further classified into High-level disinfection which is the process that destroy mycobacteria, vegetative bacteria, viruses and fungi but the process cannot inactivate high numbers of bacterial spores. High-level disinfectant, further classify by FDA as a sterilant used for a shorter contact time [4].

Another type of disinfection is Low-level disinfection which is the method that renders most vegetative bacteria, some fungi, and some viruses inactive; nevertheless, it is not dependable in rendering resistant microorganisms (such as bacterial spores or mycobacteria) inactive [4].

Disinfection offers following advantages. It kills the microorganisms and pathogenic bacteria's. Disinfection provides a cost-effective method of using chemicals for cleaning. The agents are by far available and are simple to handle.

Management of hazardous waste is a major disadvantage of disinfection. In addition, it can cause irritation to skin and/or allergy in sensitive individuals.

The major limitation of disinfection is that it cannot kill bacterial spores [5]. Other limitation depends upon the type of disinfectant used and the type of disinfectant used to disinfect the surface. For example, commercially available wipes can transfer bacteria if reused [6]. Formaldehyde has poor penetration power so it limits its use on curved and complicated surfaces. In addition, it should be used in sufficient quantity to exhibit its disinfectant qualities [7]. The use of hydrogen peroxide is limited because of allergic reaction insensitive individuals [8].

Ideal properties of disinfectant should be:

- A broad spectrum of activity, meaning it is effective against all microbes. Fast acting.
- Effective in the presence of organic materials, suspended solids, and other components of the matrix or sample; nontoxic, soluble, nonflammable, and nonexplosive.
- Adaptable to different surfaces and materials.
- For the duration of the desired exposure, it is stable or persistent.
- Leaves behind a residual, which is occasionally unwanted.
- Simple to produce and use.

Standard precautions

Standard precautions comprise a number of infection control practices intended to limit the spread of diseases that might be acquired from contact with such body fluids and blood, or by direct entry into mucous membranes and cutaneous or damaged/compromised skin [9] (Figure 1).

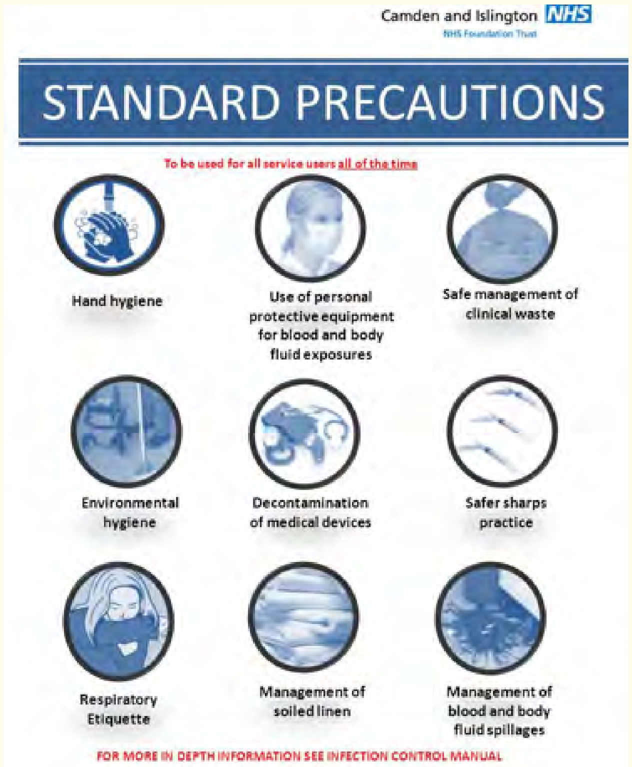

Figure 1: *Standard precautions.*

Techniques employed for disinfection

As per the availability of resources and need of the area, different methods can be useful for disinfection.

- **Chemical disinfection**: These are the agents like glutaraldehyde and phenolic compounds. They could be used to clean instruments, operatories and hand disinfection. Chemical disinfectants includes phenolic compounds, chlorine compounds, e.g. hypochlorites; dichloroisocyanurates (NaDCC), Alcohols, Iodine compounds, Biguanide compounds, e.g. chlorhexidine, Triclosan (2, 4,4'- thrichlor-2'-hydroxydiphenylether), Quaternary ammonium compounds, Glutaraldehyde and Hexachlorophene.
- **Steam disinfection:** Steam disinfection is used to disinfect operatory and clinics. They can be dispended as aerosol or vapors in order to reduce the suspended microorganism's quantity [10]. The steam ability to kill microorganisms is hidden on its heat. The steam is applied to the surface, providing enough energy to break soil bonds and release contaminants into the atmosphere, which can be removed by using vacuum or wiped off. They use little water and effectively used on hypoallergenic surfaces [11].
- **Washer-disinfection:** This system uses high temperature other than chemical disinfection by using automatic system, which cleans the instruments thermally. It offers the advantage of automatically controlled system followed by monitoring of the process of disinfection by maintaining proper record through printout and memory cards [12].

Factors affecting disinfection

Microbes are present everywhere from the mucous membranes lining the different organs to the inner gut lining. They can cause serious life threatening infections, which can leads to death. Their prompt and effective control leads to the prevention and control of diseases and infections. The use of prompt disinfectants enables humans to control on these factors. Effective disinfection depends on the following factors:

- Intrinsic factors.
- Extrinsic factors.

Intrinsic factors are the factors, which includes inherent microbial qualities which resist against disinfection.

The intrinsic factors include:

- Number of microorganisms.
- Location of microorganisms.
- Innate resistance of microorganisms.

Extrinsic factors are the factors, which includes external physical environment.

- Concentration and potency of disinfectants
- Physical and chemical factors.
- Organic and inorganic matter.
- Biofilms.
- Duration of exposure.

Intrinsic factors

Number of microorganisms

The number of microorganisms is directly proportional to the activity required of disinfectants. The greater the number of microbes the more powerful and potent disinfectant required. Spaulding evaluated and applied similar test conditions on two groups of microorganism with variable time and observed that greater time was taken if the quantity of microorganisms increased. This focuses on the need of meticulous cleaning and disinfection of instruments before they kept for sterilization. It has been evident from the research that it is difficult to clean clumps of bacteria rather than mono dispersed microbes [13].

Location of microorganisms

Microorganisms may hide in areas with curves and joints, especially in complex medical instruments. Therefore, instruments with complex architecture and design must be disassembled before placement in the disinfectant. All air pockets should be removed and instruments should be placed for recommended exposure time in order to make the disinfection effective. Manufacturers should be encouraged to design instruments with easy design and handling [14].

Innate resistance of microorganisms

The innate resistance of microorganisms varies greatly. Different microorganisms have different mechanisms through which thy develop resistance against disinfection and sterilization processes. For instance gram negative bacteria have an exterior membrane that functions as a barrier to the uptake of disinfectants, spores have a core and cortex that hinders the influx of disinfectants, and mycobacterium have a waxy wall. The outer membrane covering the gram negative bacteria prevent disinfectant to pass through them [15,16].

Extrinsic factors

Concentration and potency of disinfectants

The concentration and potency of disinfectants is directly proportional to the efficacy of disinfectant and shorter time is required to produce disinfection. But this is not applicable to all disinfectants. For instance, the concentration exponents of phenol and quaternary ammonium compounds are 1 and 6, respectively. As a result, disinfecting a phenol solution twice as long is required when halving its concentration, whereas disinfecting a quaternary ammonium compound solution twice as long is required when halving its concentration [17-19].

The contact time required for the germicide to work is highly dependent on its strength and is therefore an important factor for effectiveness in disinfection. Spaulding showed this principle by demonstrating that a 70% isopropyl alcohol solution was capable of killing 104m of tuberculosis organisms within 5 minutes with the mucin-loop test, while the same amount of microbial elimination with a 3% phenolic solution would take 2 - 3 hours to accomplish [20].

Physical and chemical factors

The efficacy of some disinfectants is dependent on several physical and chemical factors. They include pH, temperature, water hardness and relative humidity.

pH

The pH of a disinfectant may alter the cell surface of microorganisms and change the chemical activity of the disinfectant. The antimicrobial effectiveness of glutaraldehyde and quaternary ammonium compounds is increased when the pH is elevated. In contrast, antibacterial activity at elevated pH values decreases for some other disinfectants, such as phenols, hypochlorites, and iodine [21].

Temperature

According to one study, there are three types of disinfectant:

a) Disinfection power remains unchanged by temperature changes.
b) Disinfection strength is roughly doubled as temperatures climb from 20 to 37°C.
c) The same temperature increases enhanced disinfection l efficacy by up to ten or twenty times [22].

Water hardness

Water hardness, (a high level of divalent cations), reduces the rate at which disinfectants are killed because the disinfectant and the divalent cations (such calcium and magnesium) in the hard water combine to create insoluble precipitates [23,24].

Relative humidity

Relative humidity is the solitary most significant aspect, which manipulates the commotion of gaseous disinfectants, such as chlorine dioxide, ethylene oxide and formaldehyde [25].

Organic and inorganic matter

Serum, blood, pus, feces, or lubricating material is examples of organic debris that can easily compromise the effectiveness of disinfectants in two ways.

First, the organic matter and disinfectant react chemically with each other and the quantity of available active disinfectant is less. This is usually happen with chlorine and phenolic compounds.

Second is the organic matter act as a barrier, which physically stops the penetration of disinfectant [25,26].

The inorganic materials act as barriers by forming salt crystals on the surface of instruments and devices and hence decreasing the efficiency of disinfectant [27-29].

Biofilms

Biofilms are the tightly adherent communities of microorganisms that are tightly bound together and cannot be separated easily. After the formations of biofilms microbes are develop resistance to disinfectant by creating variation in genotype of bacteria, producing neutralizing enzymes, altering physiological gradients within the biofilm and older biofilms are less prone to effective sterilization. They can cause serious problems in immunocompromised patients and those having indwelling catheters. Biofilms have been identified on a range of medical devices, including contact lenses, pacemakers, hemodialysis machines, urinary catheters, central venous catheters, and endoscopes. They have also been identified in equipment like whirlpools and dental unit waterlines [30].

Duration of exposure

A general rule is greater the duration of exposure greater will be the efficacy of sterilization. By law, all appropriate label instructions on EPA-registered products must be observed.

Monitoring of disinfection accuracy

There are various methods through which accuracy of disinfectant can be assessed [31]. They are electronic and camera-based systems, ionizing radiation, UV Systems.

Electronic and camera-based systems

Electronic and camera-based systems can check hand hygiene practices around the clock without any tendency to provoke a Hawthorne effect, providing much greater detail than any observer might ever manage on hand hygiene compliance [32].

Ionizing radiation

Ionizing radiation is an effective tool, which provides cost effective alternate to other methods. The critical dose needed to stop microorganisms from growing again was established after ionizing radiation was used to inactivate the bacteria [33].

UV systems

The serial difference of disinfection competence observed in on-site UV treatment system was prejudiced by balanced solid, temperature, and precipitation, whereas, steady standards were observed in ionizing radiation. Higher energy is needed than with ionizing radiation for disinfection when employing ozone and ultraviolet light [34,35].

Modern technologies for disinfections of environmental surfaces in hospital

New liquid disinfectants

It has been demonstrated that a new sporicidal disinfectant that understands both hydrogen peroxide and per acetic acid reduces bacterial numbers on surfaces more effectively than a quaternary ammonium disinfectant. The substance has a vinegar-like fragrance. The novel product has given hospitals a good substitute to sodium hypochlorite when utilizing a microbial disinfectant.

The production of an electrolyzed water (hypochlorous acid) disinfectant involves electrolyzing a salt and water solution. It has been demonstrated to significantly lower the levels of bacteria on surfaces near patients [36,37]. Electrolyzed water has been highly effective in reducing staphylococcal and other bacterial contamination on equipment and surfaces around the patient when used as a spray [38]. An advantage is that there are no toxic residues. The reactive oxygen species produced by such systems have bactericidal effects against many types of pathogens [39,40].

New methods for applying disinfectants

Techniques for sanitizing surfaces with liquid disinfectants [41,42]. According to certain research, microfiber or ultra-microfiber cloths are more effective at cleaning than mops or regular cotton rags [43,44]. However, it seems that the effectiveness of microfiber wipes varies [41,45]. Furthermore, there is proof that they may actually transfer microbes to other surfaces if not handled appropriately [46,47].

Self-disinfecting surfaces

One novel approach to inhibition of bacterial growth or disinfection of hospital surfaces is the "self-disinfecting surface". Such a surface is formed by depositing compounds that exhibit antimicrobial activity for a protracted period of time or by coating materials with heavy metals, such as copper or silver [48,49]. Silver combines with sulfhydryl and disulfide groups in microbial cell wall proteins and causes cell death. Copper, on the other hand, provides antibacterial activities through the creation of reactive oxygen species that further damage microbial proteins and nucleic acids. Scientific researches also revealed that introducing copper alloys onto equipment surfaces substantially reduces bacterial contamination [50,51].

Organosilane compounds, which combine a surfactant with a quaternary ammonium group as an antimicrobial component, are constructed with the idea of reducing bacterial contamination. These compounds work for weeks or months after applying to the surface and continue to ensure long-term antimicrobial protection [52,53].

Light activated photosensitizer

A few research have reexamined the possibility of employing UV radiation to produce reactive oxygen species that can disinfect surfaces and putting light-activated photosensitizers, including nanosized titanium dioxide, to surfaces [54,55]. It has been demonstrated that activated titanium dioxide exhibits varying antibacterial efficacy, with agents' absolute liability against microorganisms.

No touch room decontamination methods

Numerous systems with a diameter ranging from 2 to 12μ have been evaluated for aerosolized hydrogen peroxide systems that use 3 to 7% hydrogen peroxide with or without the inclusion of silver ions. These systems are injected into a room and then passively aerated. Although spores were not entirely eliminated in some tests, these systems have been demonstrated to minimize microorganisms, often resulting in a 4 log10 reduction of spores. There are currently no randomized controlled trials evaluating the effectiveness of these systems in preventing infections linked to healthcare, as is the case with many other infection control measures.

Hydrogen peroxide vapor

A "dry gas" vaporized hydrogen peroxide system using 30% H_2O_2 as been compelling in killing a broad spectrum of microbes, including *Mycobacterium tuberculosis, Mycoplasma, Acinetobacter, Clostridioides difficile, Bacillus anthracis*, viruses, and prions [56-58].

The micro-condensation hydrogen peroxide vapor system that uses 35% hydrogen peroxide has also been established to be an effective method for removing major infections like MRSA, VRE, *Klebsiella, Acinetobacter, C. difficile, Serratia, Mycobacterium tuberculosis*, fungi, and viruses. This system has also been used to decontaminate the packaging of untouched medical equipment taken out from isolation rooms, which is a substitute for disposal [59]. It has also been used in the decontamination of areas previously used by patients suffering from Lassa fever and Ebola virus infections [60,61].

Ultraviolet light device

In those rooms that the patient leaves upon terminal cleaning and discharge from a patient care room, it can be effective to deploy mobile, computer-controlled systems that utilize UV-C at a wavelength of 254 nm. These mobile devices can be preprogrammed for inactivation either vegetative bacteria or spores. Mobile UV-C systems are friendly, simple, requiring minimum additional environmental services staff education. They do not require sealing of doors and locking the room to be able to operate them, like other hydrogen peroxide vapor systems [62,63].

High intensity narrow spectrum light

High-intensity narrow-spectrum (HINS) light is a visible violet-blue light with a wavelength of 405 nm that has been examined for its disinfection efficacy on hospital rooms, surfaces, and air. This process targets intracellular porphyrins, which absorb the light, producing reactive oxygen species that in turn cause the antimicrobial effect [64,65]. It can be utilized in locations where patients are present, although its antibacterial efficacy is not as high as that of UV-C light.

Photocatalytic disinfection

The air purification system NASA uses relies on UV-activated titanium dioxide photocatalysis, which can inactivate airborne microbes and volatile organic compounds. As bacteria's such as *Staphylococcus aureus* and *Clostridioides difficile* can become aerosolized during patient care, installing these systems in patient rooms may help decrease airborne microbes and reduce their deposition on surrounding surfaces [66].

Recommendations:

- Reduce the quantity of microorganisms by scrupulous cleaning reduces the load and using an effective disinfectant with prescribed directions makes it more effective.
- It is necessary to completely immerse the instrument in disinfectant so that it can reach all parts of the instruments.
- Instruments must be disassembled completely before immersing in disinfectant.
- Biomedical engineers must be encouraged to design instruments with flat and plain surfaces to ease cleaning and disinfection.
- To achieve complete sterilization the exposure time and concentration of disinfectant should be kept at adequate in order to work against the innate resistance mechanism of sterilization.
- Thorough mechanical debridement of organic matters on the surface of instruments can make the disinfectant an effective cleaning agent.
- The duration of exposure should be adequate for sterilization.
- Instruments such as lumens and channels of endoscopic instruments should be completely immersed in the disinfectant.
- Biofilms can be removed by using chlorine based and monochloramines can deactivate microorganisms.
- Dental products, instruments, impression materials and teeth used in preclinical settings should be disinfected properly.
- Public awareness through social media.
- Protocol increments for sharp instruments and infection control.
- Seminar and lectures are conducted for awareness to infection control and sharps.

Conclusion

Controlling the factors affecting disinfection effectively reduces the growth of microorganisms, thereby significantly decreasing the incidence of diseases. It is recommended that surgical instruments and places should be disinfected repeatedly and disinfection should be monitored habitually.

Authors Contributions

M.K., M.K., S.A., F.T., A.A. study conception and design. M.K., A.A. draft manuscript. All authors reviewed the results and approved the final version of the manuscript.

Conflicts of Interest Statement

The authors have no conflicts of interest to declare.

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