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Disinfection and Sterilization in Healthcare: Essential Practices in Nursing, Dentistry, and Physiotherap

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1. Introduction to Disinfection and Sterilization

Disinfection and sterilization are fundamental concepts in the prevention of healthcare-associated infections involving invasive medical devices and procedures. These measures represent essential nursing, dental, and physiotherapeutic actions to ensure patient safety and protection of medical staff. Medical and healthcare providers are responsible for disinfection and sterilization treatments, which must comply with legal and ethical duties regarding hygiene. Historically, the prevention of healthcare-associated infections has been addressed since the middle of the 19th century with the discovery of germ theory. The emergence of antibiotics and the growing importance of invasive treatments and procedures firstly increased safety but then led to the emergence of antibiotic-resistant pathogens. Meanwhile, the importance of hygiene and disinfection and sterilization methods has continuously grown as infectious disease prevalence increases globally (Exner et al., 2020).

Disinfection and sterilization treatments result from complex interactions involving the medical devices, disinfectants or sterilants, environment, and the organisms to be inactivated. Effective disinfection and sterilization are difficult to achieve and must be carefully monitored. The disinfection and sterilization methods differ in several aspects, including the mechanism of action, effectiveness, material compatibility, and implementation complexity. Hence, dentate, dentate medical devices, and non-device medical treatments have specific relevant disinfection and sterilization methods that must consider the advantages and disadvantages. Medical devices are categorized as critical, semi-critical, and non-critical according to infection risk. Similarly, these devices, and also non-device medical treatments, can be grouped into three relevant groups regarding disinfection and sterilization methods. This introduction section outlines essential knowledge on the principles and historical development of disinfection and sterilization methods in healthcare to be considered for the design and development of safe medical devices and procedures. (Bharti et al., 2022)(Tao et al.2021)

1.1. Definition and Importance

To clearly define the terms disinfection and sterilization, disinfecting is the term used for the process that eliminates many or all pathogenic microorganisms. On the other hand, sterilizing refers to the complete destruction of all forms of microbial life. This includes bacteria, viruses, spores, and fungi (Exner et al., 2020). In healthcare, these processes are crucial in ensuring patient safety and preventing the spread of healthcare-associated infections. Adequate knowledge of the factors that need consideration before a method of disinfection or sterilization is established is imperative to promote patient safety. There are different methods of disinfection and sterilization, and factors that influence the choice of method are examined in more detail. Healthcare authorities around the world have guidelines on the importance of disinfection and sterilization in promoting optimal patient

care. Additionally, these guidelines outline the standard operating procedures for disinfection and sterilization within healthcare facilities. Operating procedures such as the type of equipment required, the processes involved, and the frequency of disinfection and sterilization are in place to ensure compliance. Healthcare personnel, especially nurses, dentists, and physiotherapists, directly involved in patient care are trained on the different methods of disinfection and sterilization. However, it is important that all healthcare personnel are trained on these definitions to ensure that everyone is informed and practices them appropriately. The aim is to ensure that disinfection and sterilization practices are carried out as stated in the guidelines, thus providing an understanding of these practices. (Garvey, 2023)(Rutala et al., 2023)(Rutala et al., 2023)

2. Microbiology Basics for Healthcare Professionals

To provide safe patient care, healthcare professionals must be able to prevent and control the spread of infection. To do so, it is essential to have a basic understanding of microbiology, the way infectious agents can be transmitted and the factors that increase the risk of infection. This knowledge will help in the effective use of disinfection and sterilization methods. Microorganisms are tiny living organisms that cannot be seen by the naked eye. They can be helpful or harmful to humans. Those that can cause diseases are called pathogens. Healthcare professionals must know the characteristics and life cycles of specific pathogens. This will help them understand how pathogens can be isolated from a host and how they can survive outside a host. Such knowledge will aid in devising effective disinfection and sterilization strategies (Yoo, 2018).

Bacteria, viruses, fungi, and parasites are the four main categories of microorganisms. Bacteria are single celled organisms. Some bacteria can be beneficial, while others can cause diseases. Viruses are a type of microorganism that can only reproduce inside the living cells of an organism. Fungi are multi-cellular or unicellular organisms. Fungal infection can occur mainly in the skin, respiratory system and nails. Protozoa and helminths are common types of parasites. Protozoa are unicellular organisms and helminths are worm-like parasites. There are various microbiological techniques to identify, isolate and detect microorganisms or pathogens. The isolation and identification of microbes from a specimen involve a number of steps including inoculation, incubation, isolation, inspection, identification and information (Exner et al., 2020). The cultures should be incubated in suitable conditions, which will help the microbes grow. Of note, factors such as the procedure and site of care should be considered carefully, as they might affect chances of exposure to infectious agents. Indwelling devices should be handled prudently, as their presence can increase the risk of infection. Overall, technological advances in the biomedical field have the potential to prevent, detect and control infections, however careful consideration of other possible variables is necessary. Microbial resistance to disinfectants and sterilants is an important consideration. A disinfectant or sterilant is deemed to have failed if a pathogenic microbe survives following its application. Such failures may lead to outbreaks of infectious diseases. To mitigate the risks and implement the most appropriate processes, it is vital to fully understand how disinfectants and sterilants work. This understanding will inform the best practice and precautionary measures necessary to protect healthcare environments, particularly in sensitive areas such as those containing immunocompromised patients. (Wilson et al.2021)(Lyashchuk et al.2021)(Rudenko et al.2021)(Klawonn et al.2021)

Accurate data regarding infection rates, types of pathogens and outbreak patterns is critical for formulating appropriate control strategies. Globally, the risk factors associated with infections in the operating room, intensive care unit, emergency department, neonatal unit, dental chair and endoscopic examination unit are elucidated. Disinfection is critically examined with a focus on its definition, mechanism, efficacy evaluation and resistance concerns. The basic principles of disinfectants used in healthcare and general settings are discussed. In a similar manner, sterilization is explored, with an emphasis on the definition, procedure, monitoring and resistance associated with it. An overview of good practices in nursing, dentistry and physiotherapy environments is provided, focusing on disinfection and sterilization. The need to thoroughly understand disinfectants and sterilants before their application is emphasized, as misuse can lead to unintended consequences. (Evans et al.2021)(Shen et al., 2021)(Rehman et al.2022)

2.1. Understanding Pathogens

Healthcare-associated infections (HAI) are infections acquired by patients during their stay in a healthcare establishment. They represent a major risk for hospitalized patients, causing prolonged morbidity and mortality. Moreover, they represent an economic burden for the healthcare establishments and the society. The pathogens responsible for HAI are often multi-drug resistant organisms (MRO) (Peng Chua et al., 2022). The aggravation of this situation is the novel emergence of MRO since antibiotics are the most widely used drugs in the world. In this context, a better understanding of the pathogens' biology and the advantages and limitations of sanitizing strategies are crucial for preparing and preventing the hospital environment against the infectious threat.

Pathogens are microorganisms that can cause disease in their hosts. A critical role of pathogens in the development of healthcare-associated infections is well-recognized (Browne & G Mitchell, 2023). Understanding the basic features of pathogens is important to the development of effective prevention strategies. Pathogens are usually classified according to their taxonomy as bacteria, viruses, fungi, and parasites. Pathogens can also be classified according to their infectious ability as primary and opportunistic pathogens and according to their mode of transmission as contact, vehicle, airborne, vectorborne, and matrix pathogens. The pathogenicity's basis for different types of pathogens is also discussed.

A pathogen's life cycle consists of a series of developmental stages and transmission routes from one host to another. Understanding the life cycle and transmission route of the pathogen is essential to prevent infection by the pathogen. An infection is defined as the successful establishment of a parasitic life in a host. In general, a pathogen can cause an infection if it overcomes the host's protection (barrier and immune system). However, an infection does not necessarily result in clinical disease. Some factors contribute to the development of an infection: 1) increase in the pathogen's inoculate dose, 2) increase in the pathogen's virulence, 3) alteration in host susceptibility (e.g. co-morbidity and immunocompromised hosts), and 4) alteration in environmental conditions favorable for the pathogen. A deeper understanding of the factors involved in the infection development is important to recognize high-risk patients and high-risk situations. Preventive measures against infection should target specific pathogens. Therefore, it is necessary to understand the unique features of each pathogen. (Jones et al., 2021)(Rokas, 2022)(Pagán, 2022)

3. Disinfection Methods

Disinfectants are antimicrobial agents used to disinfect the inanimate environment and are registered by the Ministry of Health. Disinfectants can be categorized based on their chemical composition: biguanides, halogenated compounds, organic acids, oxidizing agents, alcohols, aldehydes, phenolic compounds, surfactants, and other substances. (Exner et al., 2020) recommended that disinfectants be categorized according to their effectiveness and use with respect to the microorganism spectrum. Accordingly, disinfectants can be classified as low-level disinfectants, intermediate-level disinfectants, high-level disinfectants, and sterilants. High-level disinfectants and sterilants inactivate all microorganisms, including high numbers of bacterial spores. Low-level disinfectants destroy some, but not all, mycobacteria and viruses. High-level disinfectants inactivate some, but not all, bacterial spores.

Disinfection can be routine disinfection or high-level disinfection and can be used for semi-critical or non-critical medical devices. Semi-critical medical devices should undergo high-level disinfection after each use. High-level disinfection can be accomplished by chemical or heat methods. For example, temperature 550C (dry heat) for 30 minutes is applicable for high-level disinfection of metal instruments. Additionally, in the event of soiling with blood or body fluids, dental suction tips should be subjected to high-level disinfection immediately. Hydrochloric acid 4% is used in dental suction system tubing for basic high-level disinfection. Non-critical medical devices undergo routine disinfection after each use. For example, the dental chair arm is disinfected with quaternary ammonium compound 0.2% after each patient.

Disinfectants reach microorganisms in a specific manner and in a certain time interval, and therefore a number of factors influence the efficacy of the disinfectants. These factors are concentration/strength, contact time, temperature, environmental conditions, biofilm, flow rate, and other factors. Additionally, healthcare workers must consider the side effects of chemical disinfectants. Disinfectants can be toxic if ingested or inhaled, irritating to skin and mucosa, corrosive, and sensitizing. Disinfectants must be handled with care, and proper personal protective equipment (PPE) must be worn. PPE includes, at a minimum, gloves and safety goggles; a face mask or a face shield is recommended. Wearing gloves is essential while diluting and applying disinfectants in order to protect the skin. When there is a risk of splashing, eye protection must be worn. Personal protective equipment should be used properly, e.g., disinfectant gloves should be worn over non-disinfectant gloves in contact with cleaning chemicals, to avoid cross-contamination. Proper training in disinfecting procedures, checklists, or validation of disinfecting procedures can help improve disinfection outcomes. (Ghafoor et al.2021)(Lachenmeier, 2021)(Dhama et al.2021)(Osimitz and Droege2022)

3.1. Chemical Disinfectants

Disinfection is a process to reduce the number of viable microorganisms to a less harmful level. It is mostly used in healthcare settings for the disinfection of inanimate surfaces and objects. This process may not inactivate bacterial spores and some viruses . Chemical disinfectants are substances that are capable of killing most pathogenic microorganisms under defined conditions and are recommended for application to inanimate surfaces. The equivalent agents for skin and mucous membrane are called antiseptics. The efficacy of chemical disinfectants is defined by the standard test procedures of the European Committee for

Standardization adopted by the European Union. There are different classes of chemical disinfectants based on their mechanism of action; therefore, they should be used in a specific scenario or on a specific surface.

Alcohols (ethanol or isopropanol in a concentration of 60% to 90%) inactivate most gram-positive bacteria, gram-negative bacteria, fungi, and enveloped viruses but not non-enveloped viruses and bacterial spores. Alcohols fix protein structures, leading to the formation of a protein layer that stops further penetration into the cell. This property prevents the germicidal action of alcohols when used on contaminated surfaces with high protein concentration. The effectiveness of alcohols is also greatly reduced under low humidity conditions, as nucleic acids should be hydrated for alcohols to inactivate them. Chlorine compounds such as sodium hypochlorite have a broad spectrum of efficacy against gram-positive bacteria, gram-negative bacteria, fungi, bacterial spores, and viruses. However, they have limited efficacy against mycobacteria. Chlorine compounds denature proteins and nucleic acids. Hypochlorous acid is the most germicidal active form of sodium hypochlorite, and its concentration is dependent on the pH of the solution; this acidity might explain the germicidal activity of chlorine compounds in biological fluids. Sodium hypochlorite is ineffective in inactivating enveloped viruses, while 1% sodium hypochlorite is effective in inactivating non-enveloped viruses. Quaternary ammonium compounds are effective against gram-positive bacteria, enveloped viruses, and some fungal spores but are ineffective against gram-negative bacteria and non-enveloped viruses. Quaternary ammonium compounds interact with the lipid bilayer membrane of cells, leading to the leakage of low-molecular-weight cytoplasmic components that ultimately kill the cells. The efficacy of quaternary ammonium compounds is significantly reduced in the presence of organic materials such as serum and blood. There are many other types of disinfectants in use, and careful consideration should be given for their application, as improper use may bring more harm than good. (Jones et al.2023)(Lo et al.2022)(Thakur & Vashistt, 2021)

4. Sterilization Techniques

Sterilization Techniques Decontamination of Medical Instruments: Sterilization vs Disinfection Medical instruments and surfaces must be disinfected or sterilized to prevent healthcare-associated infections (HAIs), which can significantly affect patients' health and safety, especially considering their vulnerability during dental or medical treatment. The disinfection or sterilization technique used should be adapted to the type of contamination, equipment, and surface. Sterilization is the process of ensuring that a medical instrument or surface is free of all alive microorganisms. It is critical for items classified as high-risk, which directly contact sterile body sites or tissue (e.g., endotracheal tubes, skin incision scalpels). In contrast, decontamination is the process of reducing the number of microorganisms on a surface. Items classified as low-risk only contact intact skin (e.g., BP cuffs, stethoscopes) and can simply be disinfected. Comparison of Sterilization Techniques There are several methods to achieve sterilization: steam sterilization, dry heat sterilization, ethylene oxide sterilization, and radiation sterilization. Their principles, advantages, and disadvantages are summarized below. - Steam sterilization, most commonly performed in a tabletop autoclave, uses saturated steam and is compatible with most medically used materials except for water-sensitive items or plastics. It is the fastest sterilization method. - Dry heat sterilization requires high temperatures. Although it is an effective method, it is less practical due to its slow operation. This method is only compatible with materials that can withstand high temperatures. - Ethylene oxide sterilization is mainly used for heat-sensitive items. Ethylene oxide gas penetrates the cell wall, reaching the DNA of the microorganism and killing it by alkylation. Although it is an effective and well-established sterilization method, safety concerns must be considered. Ethylene oxide is toxic and potentially explosive. Additionally, it has harmful effects on the human body, so the equipment must be ventilated thoroughly after sterilization. - Radiation sterilization is mainly used for single-use pre-sterilized medical devices. Ionizing radiation sterilizes by breaking the DNA strand. It is a safe method; however, it is only practical on an industrial scale. Considerations when Choosing a Sterilization Technique Each sterilization technique has its own compatible (or not compatible) materials. For example, steam sterilization cannot be applied to materials that are water sensitive or steam-penetration-inaccessible items. Therefore, it is crucial to choose a compatible sterilization technique to avoid equipment damage. Importance of Validating the Sterilization Process Simply having a sterilization device does not guarantee that sterilization is achieved. Therefore, it is crucial to validate the sterilization process to ensure the consistent quality. Several techniques can be used to monitor the sterilization process: - Physical monitoring: All steam sterilizers should be equipped with a physical monitoring system to guarantee that the sterilization cycle is being performed correctly. Non-graphing temperature-recording charts can be used to log the physical parameters during the sterilization cycle. - Chemical monitoring: Chemical indicators can be used to rapidly test whether the physical conditions for sterilization were met. However, there are limitations since chemical indicators cannot prove that a sterilization cycle is effective. - Biological monitoring: Biological indicators containing resistant spores can be used to confirm whether sterilization has successfully occurred. This method is considered the gold standard for sterilization efficacy testing. Concerns and Considerations of the Sterilization Method Some sterilization methods might raise environmental concerns. For instance, although ethylene oxide is a well-established sterilization method, it

must be carefully handled because it may explode easily. The sterilizer should usually be maintained below room temperature and kept frozen to avoid pressure buildup. Sterilized items should be left ventilated outside the sterilization chamber for a sufficient period to ensure that ethylene oxide gas fully escapes. When hydrogen peroxide plasma sterilization is applied, attention should be paid to corrosion since it may damage metal parts. The sterilizer should be kept away from any sensitive devices because radiofrequency electromagnetic interference might affect their normal operation. It is important to stress that having a sterilization device alone is not enough to guarantee that sterilization is achieved. Therefore, strict adherence to guidelines and protocols is essential when implementing these techniques. Education and Understanding of the Healthcare Professionals It is hoped that this review will help broaden the understanding of sterilization techniques, which are often overlooked yet crucial in preventing HAI in patient care. Although there might be a difference in point-of-view as a researcher rather than a healthcare worker who directly operates the equipment, understanding the principle is critical to ensure that things are done correctly for safety. For example, steam sterilization is usually implemented without trouble; however, in one instance where a steam sterilization device was broken and could not function properly, improper attempts to use alternative methods without fully understanding the principle raised concerns about possible damage to patient care equipment. (Garvey, 2023)(Yiek et al.2021)(Holm and Dunn2022)

4.1. Autoclaving

Autoclaving (or steam sterilization) is the sterilization technique used most widely in healthcare settings, notably in nursing, dentistry, and physiotherapy. It is also the most common method in laboratories and research institutes. An autoclave is a machine that utilizes steam under pressure to achieve the high temperature (usually around 121°C or higher) necessary for effective sterilization. Regardless of the sterilization method, to achieve effective sterilization results, the following three basic principles need to be regarded: time, temperature, and pressure. In steam sterilization or autoclaving, the sufficient time and temperature for sterilization (121°C for at least 15 minutes) are established through high relative humidity. When steam comes into contact with cooler objects, heat is transferred from the steam to those objects until equilibrium is achieved. The steam's latent heat becomes sensible heat, causing the object's temperature to rise until the desired level is reached. The steam's pressure is directly related to its temperature; therefore, to achieve high temperatures, steam is kept under pressure (Sohrab Hossain et al., 2012).

Autoclaving has many advantages over alternative sterilization methods. Besides its supportive capacity for rapid cycle processing, it is reliable and easy to use. In many facilities, nursing, dentals, or physiotherapy clinics, an autoclave machine becomes essential equipment due to its diversity in tools and materials. Autoclaving is effective for killing endospores and removing all forms of life from inanimate objects, making it perfect for use on surgical tools and items like glassware. The procedure is usually quick; by standard operating protocols, most items can be sterilized in 30-45 minutes, including preparation and temperature recovery. However, preparation is critical in ensuring effective autoclaving results. Prepared items are usually arranged in trays or baskets for loading into the autoclave. These trays are crucial in autoclaving, as they allow steam to penetrate through the instruments. Therefore, to avoid steam penetration issues, items should always be loaded in trays across (not stacked vertically) or positioned upside down whenever items are placed in jars (Panta et al., 2019). In an autoclave, there are generally two different cycles: pre-vacuum and gravity. When operating in a pre-vacuum cycle, care should be taken to always load the tray in the correct position; otherwise, it may lead to steam penetration issues. Regardless of the cycle type, consider the following points during loading: always ensure jarred items are loaded upside down, never stack metal trays vertically, and never stack objects close together (too much overlap). Additionally, ensure the door seal is clean when performing autoclave cleanup, as this can also lead to steam leakage issues (or failed cycles).

Despite its advantages, autoclaving can also present challenges. Most notably, many plastics cannot withstand the high temperatures of autoclaving, resulting in damage. However, some plastics are made to withstand higher temperatures (usually labelled as autoclaveable). Another autoclaving disadvantage is that metal tools can corrode after repeated autoclaving cycles. Even so, metal tools are meant to withstand numerous autoclaving cycles, and in most cases, it's the soap or detergent used that causes corrosion. Finally, it is also crucial to ensure that all instruments are thoroughly dried after an autoclaving cycle is completed. Failure to do so may result in water spots (especially glass items) or rusting metal items. To ensure equipment reliability, at least once a week, all autoclaves should undergo validation using biological indicators (BIs). BIs are commercially available vials containing spores of Bacillus stearothermophilus and a culture medium. To monitor each cycle, it is highly recommended to use chemical indicators (CIs), as these are more visible than BIs. CIs are commercially available strips that change color with exposure to steam or ethylene oxide gas. (Berrú et al.2021)(Sarmiento-Ordóñez & Calle…)

5. Best Practices in Disinfection and Sterilization

Disinfection and sterilization are critical in maintaining hygiene and preventing infection in healthcare settings. This overview provides best practices that nurses, dentists, and physiotherapists should follow when disinfecting or sterilizing equipment, surfaces, or patient care environments. Recently, the focus on hygiene in the healthcare environment has increased due to the threat of emerging infections and antibiotic-resistant germ transmission. Development of best practices is essential for maintaining high standards of hygiene and controlling the spread of infection in healthcare settings. In nursing, dentistry, and physiotherapy environments, a systematic approach to infection control is important for patient service design. Therefore, protocols for disinfecting and sterilizing need to be tailored to the specific clinical environment and adhered to rigorously by all staff (Exner et al., 2020).

It is crucial to train staff in best practices and educate them on the latest guidelines and procedures. New staff members should undergo an induction program that includes training in hygiene protocols. Updates on new products or changes in procedures should be provided through in-service training sessions. Regular audits should be conducted to ensure compliance with cleanliness and disinfection procedures. The audit can involve spot checking equipment cleanliness or reviewing records of disinfecting environmental surfaces. It may be necessary to test the effectiveness of disinfection procedures by conducting microbial load assessments. Infection control committees should be established to monitor compliance with disinfection protocols and provide guidance on best practices. Cleaning and disinfection protocols need to be evidence-based and tailored to specific clinical scenarios. Individualized patient care is important, as some patients may require extra attention due to increased risk of infection. The healthcare team should work together to create a culture of safety, and protocols should be developed with input from all staff. It is important to remember that “what is best for the patient” should always be the primary focus. (Assadian et al.2021)

5.1. Standard Precautions

Standard precautions are the basic infection prevention practices that should be consistently used at all times and in all healthcare settings. They were designed to protect both patients and healthcare workers as well as to prevent the spread of infection. Standard precautions apply to all patients in a healthcare setting, regardless of their infection status. Precautions are based on the premise that all patients may be potential sources of infection (Ely Tarrac, 2008). Therefore, a set of precautions goes into effect as soon as a healthcare worker has contact with the patient. Standard precautions include hand hygiene, use of personal protective equipment (PPE), safe handling of sharps and waste, and other precautions in specific situations. Compliance with standard precautions will greatly reduce the risk of cross-contamination and infection.

Healthcare workers must wash their hands when entering and exiting the patient's care area. Hands should be washed with soap and water, or use an alcohol-based hand rub when the hands are visibly soiled or after certain patient interactions. In general, the use of personal protective equipment (PPE) is always required when there is a risk of exposure to blood and other body fluids. PPE includes gloves, face shields, masks, goggles, and gowns. Sharps must be disposed of immediately after use in designated sharps containers. In addition, infectious waste must be disposed of in sealed biohazard bags and then put in designated waste bins. However, standard precautions do not apply to patients in a same-day dental surgery who are not sedated unless these patients are screened for the risk of possible infection. On the other hand, precautions are different for some procedures that may generate aerosols compared to those that don't. For instance, there is a variation in precautions used when examining a patient in a wheelchair versus examining the same patient on a stretcher. Some precautions also vary depending on patients who are on routine dialysis versus those who are on home dialysis. In addition, training on standard precautions must be conducted regularly, and new personnel must be trained and observe precautions at all times until adequately trained. It is very easy to become complacent and overlook some precautions, so ongoing training is needed to encourage vigilance. (Chang et al.2022)(Health Organization, 2021)

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