The Role of Advanced Technologies in Sterilization and Disinfection of Hospital Waste: Trends and Innovations.


Abstract

Disinfection and sterilization are indispensable processes in healthcare facilities to mitigate the risk of infections and ensure patient safety. Various methods, such as steam sterilization, ethylene oxide (ETO) sterilization, hydrogen peroxide gas plasma, and vaporized hydrogen peroxide, offer distinct advantages and limitations in terms of effectiveness, compatibility with different materials, and safety considerations. Steam sterilization is a widely utilized method due to its reliability and broad applicability, while ETO sterilization provides excellent penetration for heat- and moisture-sensitive items but poses potential health risks. Newer technologies like hydrogen peroxide gas plasma and vaporized hydrogen peroxide offer effective sterilization at lower temperatures without leaving harmful residues. The choice of method depends on factors such as material sensitivity, microbial load, and safety concerns. Proper disinfection and sterilization protocols are crucial for maintaining a hygienic healthcare environment and preventing healthcare-associated infections. Staying informed about advancements in disinfection technologies and adhering to best practices are essential for ensuring patient and staff well-being.

Keywords: Sterilization, Disinfection, Steam, ethylene oxide, non-critical items.
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Introduction

There are over 46 million inpatient surgical operations and 53 million outpatient surgical procedures performed annually in the US. As an illustration, at least 10 million gastrointestinal endoscopies are performed annually. In all of these procedures, a patient's sterile tissue or mucous membranes come into contact with surgical instruments or medical equipment. Any such surgery carries a significant risk of introducing infection. In addition to the risk of breaching host barriers, improper disinfection or sterilization of equipment increases the risk of environmental infections (such as Clostridium difficile) and person-to-person transmission of diseases like the hepatitis B virus.

Ensuring that medical and surgical instruments do not spread infectious microorganisms to patients requires achieving disinfection and sterilization through the use of disinfectants and sterilization procedures. Healthcare regulations must specify whether cleaning, disinfection, or sterilization is necessary, primarily depending on the item's intended use, as not all patient care products need to be sterilized [1].

Evidence of noncompliance with set recommendations for sterilization and disinfection has been found in numerous research studies conducted in various nations. Several infectious disease outbreaks have resulted from noncompliance with instructions derived from scientific research. This research presents a practical approach to the wise selection and appropriate application of disinfection and sterilization processes. It is based on welldesigned studies that evaluate the efficacy and effectiveness of disinfection and sterilization procedures through laboratory investigations and clinical studies. Additionally, we briefly discuss medical waste management in healthcare facilities [2].

In medical institutions, sterilization, which involves the complete eradication or destruction of all microbiological life, is achieved using chemical or physical methods. The primary sterilizing agents utilized in healthcare facilities include steam under pressure, dry heat, ethylene oxide (ETO) gas, hydrogen peroxide gas plasma, evaporated hydrogen peroxide, and liquid chemicals. The goal of sterilization is not to convey a relative meaning, but an absolute one. Unfortunately, some medical experts, as well as technical and commercial literature, refer to objects as "partially sterile" and "disinfection" as "sterilization."

Chemical sterilants are substances intended to eliminate all traces of microbiologic life, such as bacterial and fungal spores. These same germicides, when applied for shorter exposure times, might also be utilized in high-level disinfection procedures.

Disinfection is the process of eliminating most or all pathogenic germs on inanimate objects, with bacterial spores being the exception. In healthcare settings, liquid chemicals or wet pasteurization are typically used to achieve disinfection. Numerous factors influence disinfection efficacy, and each one has the potential to reduce or negate the effectiveness of the process. The type and degree of microbial contamination, the concentration and duration of exposure to the germicide, the nature of the object (e.g., crevices, hinges, and lumens), the presence of biofilms, the temperature and pH of the disinfection process, and, in some cases, the relative humidity of the sterilization process (e.g., with ETO) are some of the factors affecting the efficacy of both disinfection and sterilization [3].

It is oversimplified to state that disinfection is different from sterilization by definition since it lacks sporicidal properties. Certain disinfectants, known as chemical sterilants, have the ability to destroy spores after extended exposure (for example, three to twelve hours). Highlevel disinfectants are those that, at comparable doses and exposure times (e.g., 12 minutes for 0.55% ortho-phthalaldehyde), can destroy all microorganisms save for a significant amount of bacterial spores. While intermediate-level disinfectants may be cidal...
for mycobacteria, vegetative bacteria, most viruses, and most fungi but not necessarily for bacterial spores, low-level disinfectants may kill most vegetative bacteria, some fungi, and some viruses in a reasonable amount of time (≤10 minutes). The antimicrobial range and speed of action are the main areas where the germicides vary significantly from one another [4].

Cleaning is the removal of visible soil, such as organic and inorganic debris, from items and surfaces. This is typically done by hand, using water mixed with detergents or enzymatic solutions. Prior to high-level disinfection and sterilization, the surfaces of the instruments must be thoroughly cleaned since residual organic and inorganic elements compromise the efficacy of these procedures. Furthermore, if the filthy materials dry out or bake onto the equipment, the removal process becomes more challenging, and the sterilization or disinfection process becomes less successful or inefficient. To soften or remove blood from surgical instruments and to prevent blood from drying out, the instruments should be presoaked or cleaned. Decontamination involves removing pathogenic germs from an object to make it safe to handle, use, or dispose of [5].

Words for killing actions that end in "-cide" or "-cidal" are also frequently used. An agent that kills microorganisms, especially pathogenic organisms (sometimes known as "germs"), is called a germicide. Antiseptics and disinfectants are both included in the term "germicide." Disinfectants are antimicrobial agents used only on inanimate objects, while antiseptics are germicides administered to skin and live tissue. Preservatives are substances or materials that prevent the growth of microbes that can deteriorate things or materials biologically. Since disinfectants can harm skin and other tissues, they are rarely used for skin antisepsis. Antiseptics, on the other hand, are typically solely used on the skin. Other words that end in "-cide," such as virucide, fungicide, bactericide, sporicide, and tuberculocide, have the ability to destroy the kind of microorganism that the prefix designates. An agent that destroys bacteria, for instance, is called a bactericide [6].

In conclusion, effective sterilization and disinfection procedures are paramount in medical institutions to prevent the transmission of infectious microorganisms and ensure patient safety. Sterilization, characterized by the complete eradication or destruction of all microbiological life, is achieved through chemical or physical methods such as steam under pressure, dry heat, and ethylene oxide gas. Disinfection, on the other hand, involves eliminating most or all pathogenic germs on inanimate objects, excluding bacterial spores. Both sterilization and disinfection play critical roles in maintaining a clean and safe healthcare environment. Despite the essential nature of sterilization and disinfection, challenges such as noncompliance with recommended practices and factors affecting efficacy persist. Factors such as the type and degree of microbial contamination, exposure duration and concentration of germicides, and the nature of the objects being sterilized or disinfected can impact the effectiveness of these processes.

Furthermore, it is important to differentiate between sterilization and disinfection, as well as to understand the various levels of disinfection and their corresponding antimicrobial properties. Proper cleaning procedures are also essential before high-level disinfection and sterilization to ensure the removal of organic and inorganic debris that could compromise the efficacy of these processes. In summary, maintaining rigorous sterilization and disinfection protocols in medical institutions is crucial for preventing the spread of infections and ensuring the safety of patients and healthcare workers alike. Continued research and adherence to best practices are essential in addressing challenges and improving the efficacy of sterilization and disinfection procedures in healthcare settings.

Rational Approach:

Earle H. Spaulding developed a logical method for sterilizing and disinfecting patient care supplies and equipment approximately 45 years ago. Infection control specialists and others have effectively adopted this classification scheme since it is rational and straightforward. Spaulding believed that categorizing tools and supplies for patient care according to the
level of infection risk associated with their usage would help in understanding the nature of disinfection more easily. Although the system is still valid, certain examples of disinfection investigations involving viruses, mycobacteria, and protozoa challenge the present definitions and expectations of high- and low-level disinfection [7].

Spaulding distinguished between three categories: noncritical, semicritical, and critical.

**Critical Items:** These items are termed critical because they pose a very high risk of infection from any pathogen, particularly bacterial spores. Because any microbiological contamination could lead to the spread of disease, it is imperative that items that come into contact with sterile tissue or the vascular system be sterile. This group comprises devices used in sterile bodily cavities, such as ultrasonography probes, implants, arthroscopes, laparoscopes, and cardiac and urine catheters. Most products in this category should be purchased sterile or, if steam sterilization isn't an option, should be sterilized. If other procedures are not suitable, the object, if heat sensitive, may be treated with hydrogen peroxide gas plasma, hydrogen peroxide vapor, or liquid chemical sterilants. Various germicides are listed in Tables 301-1 and 301-2 under the headings of chemical sterilants and high-level disinfectants. These include formulations containing 2.4% or more glutaraldehyde, hypochlorous acid/hypochlorite 650 to 675 ppm free chlorine, 1.12% glutaraldehyde with 1.93% phenol/phenate, 3.4% glutaraldehyde with 26% isopropanol, 7.5% stabilized hydrogen peroxide, 2.0% hydrogen peroxide, 7.35% hydrogen peroxide with 0.23% peracetic acid, 8.3% hydrogen peroxide with 7.0% peracetic acid, 0.2% peracetic acid, 0.55% or greater ortho-phthalaldehyde, and 0.08% peracetic acid with 1.0% hydrogen peroxide. Liquid chemical sterilants can only induce sterility when cleaning is done beforehand to remove both organic and inorganic material, and when the concentration, contact duration, temperature, and pH requirements are satisfied [8].

**Semicritical Items:** Items that come into contact with non-intact skin or mucous membranes are classified as semicritical. This category includes diaphragm fitting rings, respiratory therapy and anesthesia equipment, some endoscopes, laryngoscope blades and handles, esophageal manometry probes, endocavitary probes, nasopharyngoscopes, prostate biopsy probes, infrared coagulation device, anorectal manometry catheters, and cystoscopes. All germs should be absent from these medical devices, although a trace amount of bacterial spores might be present. Chemical disinfectants for high-level disinfection of semicritical objects are needed less. The U.S. Food and Drug Administration (FDA) has approved glutaraldehyde, hydrogen peroxide, ortho-phthalaldehyde, peracetic acid, and peracetic acid with hydrogen peroxide as safe high-level disinfectants as long as the conditions affecting germicidal procedures are met. The chemical compatibility of a disinfectant with the items to be disinfected after prolonged usage must also be considered when choosing which disinfectant to use with specific patient care items [9].

**Noncritical Products**

Items that come into contact with intact skin, but not mucous membranes are considered noncritical. Since intact skin effectively inhibits most bacteria, the sterility of objects that contact intact skin is deemed "not critical." Examples of noncritical items include bedpans, blood pressure monitors, crutches, bed rails, bedside tables, patient furnishings, and floors. Quantitative research has indicated that the five most frequently touched noncritical elements in the patient environment are the intravenous line pump, bed rails, bed surface, supply cart, and overbed table. Most noncritical reusable items can be decontaminated where they are used and do not need to be transferred to a central processing center, unlike critical and some semicritical items [10].

When noncritical items are used appropriately and do not come into contact with nonintact skin or mucous membranes, there is minimal risk of transmitting infectious pathogens to patients through them. However, these items, such as bedside tables and bed rails, may contribute to secondary transmission if they contaminate healthcare personnel's hands or come into contact with medical equipment that will later contact patients. Several low-level disinfectants that can be used on noncritical items are listed in Table 301-1, with exposure durations of one minute or more specified. Many disinfectants registered with the U.S. Environmental Protection Agency (EPA) have a label claim of 10 minutes, but research has
shown that these disinfectants are effective against viruses, yeasts, mycobacteria, and vegetative bacteria at exposure times of 30 to 60 seconds. Therefore, using an EPA registered disinfectant or disinfectant/detergent at the appropriate use-dilution and a contact time of at least one minute is acceptable for cleaning noncritical medical equipment and surfaces. It is recommended to apply the germicide once to all hand-contact surfaces that need to be disinfected, as the average drying time for a germicide on a surface is one to three minutes [11].

To achieve low-level disinfection, reusable cleaning cloths, disposable wipes, and mop types such as microfiber and cotton string are frequently utilized. Microfiber mops have demonstrated better germ clearance than cotton string mops when used with detergent cleaner. However, changing the water-disinfectant mixture regularly during mopping is crucial to prevent the spread of heavy microbial contamination throughout the healthcare facility. Cotton-string mops should be laundered frequently to maintain cleanliness, ideally on a daily basis. Despite patients’ preference for clean hospitals and the common reliance on external appearance to gauge cleanliness in the US, it is important to use effective methods to assess surface cleanliness in patient rooms. Techniques such as microbiologic samples, fluorescent markers, and adenosine triphosphate (ATP) bioluminescence have been proposed for this purpose. Studies have shown that fluorescent markers and ATP bioluminescence, along with aerobic colony counts, provide more accurate assessments of cleaning efficacy compared to aerobic plate counts alone [12].

Chemical Disinfection:

In the medical setting, a diverse range of disinfectants, either alone or in combination, such as hydrogen peroxide and peracetic acid, are utilized. These include phenolics, peracetic acid, iodophors, formaldehyde, glutaraldehyde, ortho-phthalaldehyde, hydrogen peroxide (standard and enhanced), and quaternary ammonium compounds. With a few exceptions like ethanol or bleach, commercial formulations based on these substances require FDA approval or EPA registration. Each product has a defined purpose and should be used in a specific manner, emphasizing the importance of reading labels carefully to ensure proper selection and application. Attention to detail is crucial when using cleansers and disinfectants on electronic medical equipment to prevent risks such as burns to healthcare workers and equipment failures [13].

Disinfectants are not interchangeable, necessitating an understanding of their performance characteristics to choose the right disinfectant for each item and apply it effectively. Improper disinfectant selection or concentration could lead to excessive costs. Additionally, exposure to various disinfectants, including formaldehyde, glutaraldehyde, and chlorine, has been associated with occupational diseases in cleaning personnel, highlighting the importance of minimizing exposure through protective gear and adequate ventilation. Sensitized individuals exposed to airborne chemicals, including germicides, may develop asthma and reactive airway disease [14].

Alcohols, including ethyl alcohol and isopropyl alcohol, exhibit germicidal properties and are tuberculocidal, fungicidal, and virucidal. However, they lack sporicidal effect and are not suitable for sterilizing surgical and medical supplies due to their inability to penetrate protein-rich materials. Chlorine-based disinfectants, such as hypochlorites, are commonly used and come in liquid and solid forms. While effective, hypochlorites have drawbacks such as corrosiveness to metals, inactivation by organic matter, and potential release of toxic chlorine gas when mixed with certain substances. Superoxidized water, generated by electrolyzing saline, shows promise as a disinfectant or antiseptic with low environmental impact, but its efficacy can be affected by the presence of organic material [15].

Hypochlorites find widespread use in healthcare facilities for disinfecting surfaces, tonometer heads, and cleaning up blood spills. Diluted sodium hypochlorite is effective against C. difficile and is recommended for disinfecting patient rooms to lower environmental contamination and reduce infection rates. It is essential to follow proper protocols for disinfection, including preliminary decontamination, cleaning, and final disinfection to minimize the risk of infections, especially in outbreak situations [16].
In water treatment and healthcare settings, chlorine has traditionally been the disinfectant of choice, particularly effective in removing Legionella from water systems. Additionally, chloramine T and hypochlorites are utilized to disinfect hydrotherapy equipment. However, hypochlorite solutions in tap water may lose up to 40% to 50% of their free accessible chlorine content after a month if stored in closed containers with a pH exceeding 8. To maintain desired chlorine concentrations, solutions should be freshly generated or stored in closed brown bottles [17].

Glutaraldehyde, a widely accepted chemical sterilant and high-level disinfectant, has been extensively used in healthcare facilities. Its efficacy depends on factors such as age, use conditions, and formulation. Although glutaraldehyde solutions may lose effectiveness over time, newer formulations have extended shelf lives while maintaining excellent microbicidal activity. Glutaraldehyde is effective against various microorganisms, but certain species like mycobacteria exhibit relative resistance. Dilution during use and inadequate rinsing after disinfection can compromise its efficacy and pose health risks, emphasizing the importance of proper monitoring and handling [18].

Hydrogen peroxide and its improved formulations have gained popularity for disinfection in healthcare settings due to their stability and efficacy against a wide range of microorganisms. Enhanced hydrogen peroxide products have demonstrated superior effectiveness and faster action compared to standard formulations, making them suitable for disinfecting environmental surfaces and patient care objects. Lower concentrations are used for low-level disinfection, while higher concentrations are employed for high-level disinfection of medical devices. These products are considered environmentally friendly, safe, and effective alternatives to traditional disinfectants like glutaraldehyde [19].

Iodophors, such as povidone-iodine, are widely used as disinfectants and antiseptics in medical settings due to their sustained-release of free iodine, which maintains germicidal efficiency while being relatively non-toxic and non-irritating. However, they should be diluted according to manufacturer instructions for optimal antibacterial activity, and care should be taken when using them on silicone catheters due to potential negative effects. Ortho-phthalaldehyde (OPA) is an FDA-approved high-level disinfectant known for its excellent microbicidal action, surpassing glutaraldehyde in mycobactericidal activity. OPA offers advantages such as minimal irritation, stability over a wide pH range, and no activation requirement, but it may cause skin staining if mishandled [20].

Peracetic acid, or peroxyacetic acid, is a rapid-acting disinfectant effective against various microorganisms. It breaks down into harmless compounds, making it environmentally friendly. However, it can corrode certain metals and should be used with caution. Peracetic acid combined with hydrogen peroxide has shown bactericidal properties and is used for disinfecting medical devices like hemodialyzers. Phenolics, derived from phenol, have a long history of use in hospital disinfection. Commonly used phenolics exhibit broad-spectrum antimicrobial activity against bacteria, fungi, viruses, and mycobacteria. Each of these disinfectants has specific benefits and drawbacks, and their use should be tailored to the intended application, following manufacturer instructions for proper dilution and application methods to ensure effectiveness and safety [21].

Phenolic germicides are EPA-registered for disinfecting non-critical medical equipment and surfaces, but they are not FDA-approved for semi-critical items. Their use in nurseries has raised concerns about hyperbilirubinemia in infants and increased bilirubin levels when phenolics are used according to recommended dilutions. Therefore, caution is advised when using phenolics in areas where infants are present, and careful cleaning with water and drying is necessary for baby bassinets and incubators if phenolics are used. Quaternary ammonium compounds are commonly used as surface cleaners but have limitations in terms of their effectiveness against certain microorganisms, particularly mycobacteria and hydrophilic viruses. They are suitable for routine environmental cleaning but may not be sufficient for disinfecting certain medical equipment. Careful selection and use of quaternary ammonium compounds registered with the EPA are recommended for cleaning medical equipment that comes into contact with intact skin [22].
Pasteurization is effective for destroying harmful microorganisms except bacterial spores, making it a suitable alternative for chemical disinfection in certain situations, such as respiratory therapy and anesthetic equipment. Ultraviolet (UV) light has been proven effective for killing microorganisms and is used for air and surface disinfection in healthcare settings. UV light can be used for low-level disinfection of ultrasound probes when in contact with the patient's skin, but higher-level disinfection is recommended for probes in contact with mucous membranes or non-intact skin. UV light has shown efficacy in decontaminating surfaces in hospital rooms, although organic debris can reduce its effectiveness. Far-UV radiation has also been tested for room decontamination and has shown promise in quickly killing pathogens, including C. difficile spores, on surfaces. However, its efficacy may be reduced in the presence of organic debris [23].

**Sterilization:**

Because the majority of medical and surgical equipment used in healthcare institutions are constructed of heat-stable materials, heat—specifically, steam sterilization—is utilized to sterilize it. However, since 1950, the number of medical tools and gadgets composed of materials (like plastics) that need to be sterilized at low temperatures has increased. Since the 1950s, ETO has been utilized for medical equipment that is sensitive to heat and moisture. Medical equipment has been sterilized using several novel low-temperature sterilization techniques developed in the last 15 years, such as evaporated hydrogen peroxide and hydrogen peroxide gas plasma. This section examines sterilizing technologies that are utilized in healthcare and offers suggestions for how best to use them while processing medical devices [24].

In order to stop the spread of disease linked to the usage of an object, sterilization eliminates all bacteria on its surface or in its fluid. Despite the substantial risk of disease transmission associated with using insufficiently sanitized vital objects, documented pathogen transmission linked to such things is extremely uncommon. This is probably because the sterilizing procedures employed in medical facilities have a large margin of safety. The likelihood of sterility for each item to be sterilized is used to define what is considered "sterile." This probability, sometimes known as the product's sterility assurance level (SAL), is the likelihood that a single viable bacterium will exist on a product following sterilization. Typically, SAL is expressed as $10^{-n}$. For instance, the SAL would be $10^{-6}$ if there was a one in a million chance that a spore would survive. In the US, dual SALs (e.g., $10^{-3}$ SAL for drainage bags and blood culture tubes; $10^{-6}$ SAL for scalpels and implants) have been utilized for many years. The selection of a $10^{-6}$ SAL was entirely subjective and did not result in any unfavorable consequences (e.g., patient infections) [25].

Critical items are medical instruments that come into contact with sterile bodily tissues or fluids. When using these things, they should be sterile because any microbiological contamination could trigger the spread of disease. These products include implanted medical devices, biopsy forceps, and surgical instruments. Steam sterilization, which has the biggest margin of safety due to its consistency, lethality, dependability, and least impact from organic/inorganic soils, is advised if these products are heat resistant. However, low-temperature sterilizing techniques (such as ETO, hydrogen peroxide gas plasma, or evaporated hydrogen peroxide) are necessary for reprocessing heat- and moisture-sensitive objects [26].

**Sterilization with Steam**

Moist heat, in the form of saturated steam under pressure, is the most popular and reliable sterilizing procedure available. In addition to being nontoxic, affordable, and swiftly sporicidal and microbicidal, steam sterilization also heats and penetrates fabrics quickly (see Table 3013). Steam sterilization, like all sterilization methods, has some negative effects on some materials. These include increased hardening times (five to six times longer) for plaster casts, a decrease in light transmission for laryngoscopes, and corrosion and combustion of lubricants related to dental handpieces. The fundamental idea behind steam sterilization in an autoclave is to subject every object to direct steam contact for the designated amount of time at the necessary temperature and pressure. Steam sterilization
involves four key parameters: steam, pressure, temperature, and time. Dry saturated steam with entrained water (dryness fraction ≥97%) is the best steam to use for sterilizing. The process of applying pressure helps to reach the high temperatures required to swiftly destroy microbes. Achieving a certain temperature is necessary to guarantee the microbicidal activity. The two typical temperatures for steam sterilization are 132°C (270°F) and 121°C (250°F). To kill germs, these temperatures—as well as other high temperatures—must be maintained for a short period of time. The recommended minimum exposure times to sanitize wrapped medical supplies are 4 minutes at 132°C in a prevacuum sterilizer or 30 minutes at 121°C in a gravity displacement sterilizer. The type of material (metal versus rubber, plastic, or anything with lumens), whether the item is wrapped or unwrapped, and the type of sterilizer all affect how long an item takes to sanitize at consistent temperatures [27].

The gravity displacement autoclave and the high-speed prevacuum sterilizer are the two primary varieties of steam sterilizers, also known as autoclaves. As steam is lighter than air, it pushes air out of the bottom of the sterilizing chamber down the drain vent when it is admitted from the top or sides of the chamber in the earlier method. Laboratory media, water, pharmaceuticals, regulated medical waste, and nonporous materials with direct steam contact are the main materials processed by gravity displacement autoclaves. Due to insufficient air removal, the penetration time into porous materials is extended when using gravity displacement sterilizers. Similar to gravity displacement sterilizers, high-speed prevacuum sterilizers also have an ejector or vacuum pump to guarantee that air is removed from the sterilizing chamber and load before steam is entered. One benefit of using a vacuum pump is that steam may enter porous loads almost instantly [28].

The steam cycle is observed by physical, chemical, and biological sensors, just like other sterilizing systems. Temperature, time at temperature, and pressure are typically measured on a printout (or graphically) for steam sterilizers. Chemical indicators are usually integrated within the pack or attached to the exterior to track temperature or time and temperature. A biological indicator comprising Bacillus stearothermophilus (formerly known as Geobacillus stearothermophilus) spores is used to track the efficacy of steam sterilization. Positive spore test findings are very uncommon and may be the result of device malfunction, insufficient steam delivery, or operator error [28].

Outpatient, dental, and remote clinics use portable steam sterilizers. Small instruments like hypodermic needles and syringes, as well as dental tools, are intended for use with these sterilizers. Physical, chemical, and biological indicators should be used to track the sterilizer's capacity to reach the physical parameters required for sterilization. Even when it is not necessary to stop the spread of pathogens, steam sterilization should be applied whenever feasible to all heat- and moisture-resistant critical and semicritical goods (such as anesthesia equipment and respiratory therapy supplies). Sharps containers and microbiologic waste are also sterilized in healthcare institutions using steam sterilizers; however, gravity displacement sterilizers need extra exposure time for these materials [28].

Quick-Use Steam Sanitization: Underwood and Perkins initially described "flash" steam sterilization as the disinfection of an unwrapped object in a gravity displacement sterilizer for three minutes at 132°C and 27 to 28 pounds of pressure. It was designed for use with instruments (such dropped instruments) when the recommended package technique of sterilizing an item is not feasible. The shortened exposure period of the unwrapped instrument gave rise to the word "flash." The phrase "flash sterilization" is outdated and does not adequately characterize the range of steam sterilization cycles that are currently employed to treat goods that are not meant to be kept for future use. The smallest amount of time between a sterilized item being removed from the sterilizer and its aseptic transfer to the sterile field is known as "immediate use." This suggests that the sterile object is utilized for the intended purpose and in a way that reduces its contact with airborne and other environmental pollutants. It is necessary to adhere to the same crucial reprocessing procedures (such as cleaning, disinfection, rinsing, and aseptic transport from the sterilizer to the point of use). It is not advisable to utilize steam sterilization for expediency, to avoid buying enough instrument sets, or to save time [29].
"Gas" of Ethylene Oxide Sterilization

ETO is an explosive and flammable colorless gas. The concentration of gas (450–1200 mg/L), temperature (37°C–63°C), relative humidity (40–80%; water molecules transport ETO to reactive sites), and exposure duration (one to six hours) are the four key factors (operational ranges) that affect how well ETO sterilization works. Temperature and gas concentration increases may, under some conditions, reduce the time needed to reach sterilization. The main drawbacks of ETO are the long cycle time and potential risks to patients and staff; however, its high penetration, ability to sterilize occluded areas in medical items, and ability to sterilize heat- or moisture-sensitive medical equipment without negatively impacting the material used in the devices are its main advantages [30].

Acute exposure to ETO can cause depression of the central nervous system and irritation of the skin, eyes, gastrointestinal, or respiratory tracts. Prolonged inhalation has been associated with cataract development, cognitive decline, neurological disorders, and debilitating polyneuropathies. Hematologic abnormalities, an increased risk of spontaneous miscarriages, and a variety of malignancies have all been related to occupational exposure in healthcare institutions. ETO needs to be regarded as a recognized human carcinogen.

Due to its advantageous qualities, ETO has been widely used for sterilizing heat- and moisture-sensitive medical devices because there were few other options. For large capacity sterilizers fed by tanks, two ETO gas mixes are offered to replace ETO-chlorofluorocarbon (CFC) mixtures. One mixture consists of 91.5% CO2 and 8.5% ETO, while the other is a drop-in substitute for CFC made of HCFC and ETO. However, these mixtures will be phased out by the end of 2013. 100% ETO is an alternative to pressurized mixed-gas ETO systems [30].

Numerous studies have shown that ETO has strong microbicidal action, and published reports have summarized these findings. While bacterial spores—particularly those of B. atrophaeus— are more resistant than other microbes, ETO inactivates all microorganisms. However, organic compounds, inorganic salts, lumen length, and lumen diameter can all affect how efficient ETO sterilization is. For instance, ETO is ineffective at inactivating contaminated spores in endoscope channels or lumen test units, despite not being frequently employed for endoscopic reprocessing. When dental handpieces are exposed to ETO after being contaminated with Streptococcus mutans, ETO failure has also been reported. Steam sterilization is the preferred method for dental handpieces [30].

Plasma of Hydrogen Peroxide Gas

A new sterilizing technique based on plasma and hydrogen peroxide was developed in 1987 and put on the market in the US in 1993. Gas plasmas are created in an enclosed chamber under deep vacuum by using radiofrequency or microwave energy to excite the gas molecules (hydrogen peroxide) and produce charged particles, many of which are in the form of free radicals (hydroxyl and hydroperoxyl). Resistance bacterial spores are among the many germs that can be rendered inactive by this procedure. Hydrogen peroxide gas plasma can be used to sterilize objects and materials that cannot withstand high temperatures and humidity, such as some polymers, electrical equipment, and metal alloys that are prone to corrosion. The majority of medical devices and materials evaluated (>95%) have shown compatibility with this technology [31].

Vaporized Hydrogen Peroxide

Vaporized hydrogen peroxide is utilized in a new low-temperature sterilization system to sanitize reusable metal and nonmetal medical equipment. A large variety of medical devices and materials, such as polypropylene, brass, and polyethylene, are compatible with the system. Only water vapor and oxygen are produced, hence no hazardous byproducts are created. However, this method is unable to disinfect gastrointestinal endoscopes or bronchoscopes at this time. Spores, viruses, mycobacteria, fungus, and bacteria have all been demonstrated to be effectively killed by vaporized hydrogen peroxide [32].
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Conclusions

In conclusion, disinfection and sterilization are critical processes in healthcare settings to prevent the spread of infections and ensure patient safety. Disinfection involves reducing the number of pathogens on surfaces to a level where they are unlikely to cause disease, while sterilization eliminates all microorganisms, including bacterial spores, from objects and materials. Various methods are employed for disinfection and sterilization, each with its own advantages and limitations. Steam sterilization, for example, is highly effective, reliable, and widely used for heat-resistant materials, but it may not be suitable for heat- or moisture-sensitive items. Ethylene oxide (ETO) sterilization offers excellent penetration and is ideal for such sensitive items, but it carries potential risks to both patients and staff due to its toxicity. Hydrogen peroxide gas plasma and vaporized hydrogen peroxide are newer technologies that provide effective sterilization at low temperatures without leaving harmful residues. The choice of disinfection or sterilization method depends on factors such as the type of material being processed, its heat and moisture sensitivity, and the level of microbial contamination. Additionally, safety considerations, cost-effectiveness, and regulatory requirements play important roles in selecting the appropriate method. Overall, proper disinfection and sterilization protocols are essential for maintaining a safe and hygienic healthcare environment, reducing the risk of healthcare-associated infections, and ensuring the well-being of patients and healthcare workers alike. It is crucial for healthcare facilities to stay informed about advancements in disinfection and sterilization technologies and to adhere to best practices to safeguard public health.

References

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