

Review of Disinfection and Sterilization – Back to the Basics

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In-depth knowledge of disinfection and sterilization is a key component of infection control. Sterilization completely removes a spore, whereas disinfection cannot. Disinfectants are classified as oxidants and non-oxidants. The decision regarding which method to apply is based on Spaulding's classification. In this article, disinfection and sterilization are thoroughly reviewed, and extensive information from basic to practical points is discussed.

Key Words: Disinfection; Sterilization; Infection control

Introduction

The main purpose of infection control can be briefly summarized as blocking the transmission of microorganisms or pathogens [1]. Blocking should be performed in two directions. The first is prevention of vertical transmission, and the other is prevention of horizontal or lateral transmission. Vertical transmission is the propagation of pathogens from generation to generation. Proper use and regulation of antibiotics is essential to prevent vertical transmission, requiring antibiotic stewardship.

Lateral transmission is the transfer of resistance of a pathogen to other pathogens of the same generation, or propagation and expansion of the pathogen into its surroundings [2]. Preventing this lateral transmission to the greatest extent pos-

sible is a practical point in terms of infection control. Methods to block lateral transmission include health care workers' hygiene management, with procedures such as hand hygiene, and infection control of the environment, involving procedures as cleaning and disinfection. Knowledge of disinfection or antisepsis and sterilization is required for these measures [3-7].

Doctors specializing in infection control who serve as medical directors have a solid knowledge of pathogens or antibiotics, but less knowledge of or interest in disinfection or sterilization. Therefore, the purpose of this paper is to investigate in detail sterilization and disinfection techniques to which less attention has been paid, starting with the basic knowledge.

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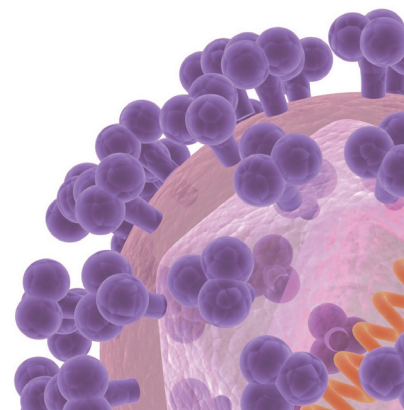
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Basic knowledge to understand disinfection and sterilization

1. Difference between disinfection and sterilization

Both disinfection and sterilization remove pathogens. The key to distinguishing the two techniques is the endospore. Removing pathogens but leaving endospores is considered disinfection, while completely destroying both endospores and pathogens is considered sterilization [3]. Therefore, it is necessary to understand when it is appropriate to apply disinfection or sterilization.

2. Atomic number and electrons

What is this basic knowledge for? Disinfection and sterilization occur at the molecular level. Disinfection and sterilization require electrons for oxidation, acidification, and coagulation. Therefore, basic knowledge of atomic number and electrons is required.

Atoms have protons with a positive charge and neutrons in the nucleus, and the same number of electrons (with a negative charge) as that of protons orbit in the outer shell. Electrons, however, do not have a fixed orbit. Electrons are located somewhere in a cloudy space, with a possibility of being located within the space surrounding the nucleus of the particular atom. An atom possessing the same number of electrons as that of protons is based on the premise that the atoms are not ionized. The number of protons is the atomic number. The mass number is the sum of the number of protons and the number of neutrons. For example, carbon (C) has an atomic number of 6 and a mass number of $6 + 6 = 12$.

Is this correct?

Wrong.

The number of protons and the number of neutrons is not always the same. An element with a different number of protons and neutrons is an isotope. For example, C has an atomic number of 12 (^{12}C), which is common, but it also has an atomic number of 14 (^{14}C), with two more neutrons.

3. Ion, Oxidation, and reduction

What is this basic knowledge for? It is necessary to know how each atom acts in disinfection and sterilization.

The ion is a state in which the number of electrons is not

equal to the number of protons in an element. This phenomenon occurs because the valence shell of the atom is only stabilized at the energy level in which it is filled with eight electrons (octet rule). Therefore, the atom releases the remaining electrons or takes the missing electrons to fill the valence shell with eight electrons. When an atom loses one of the outermost electrons, the number of protons becomes greater than that of electrons. Therefore, the net charge becomes positive, and the element is called a cation. In the periodic table, atoms belonging to group 1 are representative examples. Na and K have only one outer shell electron; thus, for these elements, it is much more natural to lose one electron rather than to take seven electrons.

On the other hand, when an element takes one outer shell electron, the number of electrons becomes greater than that of protons. Therefore, the net charge becomes negative, and the element is called an anion. A representative example is a halogen belonging to group 17 in the periodic table, which is described below.

Oxidation refers to the action of taking electrons. Substances that take electrons from an element are oxidants. Reduction refers to the opposite action. Oxidation and reduction are two important mechanisms in disinfectants and sterilants, and details of each formulation are discussed later in the sections on classification and mechanisms of disinfectants and sterilants.

4. Halogen

What is this basic knowledge for? A considerable number of disinfectants contain halogens, especially chlorine (Cl). As halogens comprise a large proportion of disinfectants, it is worthwhile to know the nature of these elements. It is also to understand the mechanisms of disinfection and sterilization by oxidation.

In the term halogen, *hal* means sea water or salt, and *gen* means production. That is, halogen denotes substances that produce salts. Fluorine (F), chlorine (Cl), and iodine (I) are the main halogens in the disinfection category. Fluorine means *fluere* in Latin and flow in English. Chlorine means greenish-yellow color in Greek, and this name is given because the color of the chlorine gas is yellow. Iodine means violet color in Greek. Because halogens belong to the periodic table group 17, seven of the eight outer shell electron positions in halogen are occupied, and only one remains. Therefore,

taking only one electron from another element and filling the remaining space leads to compliance with the octet rule. To accomplish this, halogens select one of two methods:

- Halogens pair with other halogens to achieve an octet. Thus, Cl₂, I₂, Br₂, and F₂ appear.

- Halogens take electrons from other elements with a very strong force, which means that the force to oxidize other elements is quite strong. The easiest elements from which halogens can take electrons are metals belonging to group 1, such as Na and K, which have only one electron in the outer shell. Therefore, when halogens encounter these metals, they immediately take the electrons to make salts such as NaCl and KI. How do halogens appear in our eyes? The locations where halogens are in contact crackle into fire. For example, if an unfortunate situation is caused by an individual breathing in chlorine gas, the palate, airway, esophagus, and lower respiratory mucus are instantly eroded and destroyed. In other words, halogens are poison gases. The first chemical weapon in history of war was the chlorine gas used by France and Germany in the First World War. When chlorine becomes an anion, it is chloride (Cl⁻), and it is inactive because it has become a stable element conforming to the octet rule by taking a single electron. Halogens are very strong oxidizing substances that indiscriminately destroy the cellular protein, nucleic acid, and cell wall or membrane of microorganisms. Halogens perform disinfection through disruption of oxidative phosphorylation, which is the most important process in cell survival.

5. Oxygen and radicals

What is this basic knowledge for? It is necessary to understand the mechanism of disinfection by oxidation.

Most people consider oxygen a beneficial gas.

However, contrary to this common perception, oxygen is not a very favorable element in nature for living organisms. Oxygen did not exist on Earth from the beginning. Thus, following the initial appearance of oxygen on Earth, almost all living organisms performing anaerobic metabolism became extinct, and living organisms that benefited from oxygen survived. Those that survived were aerobic bacteria, some of which moved into other eukaryotes and became mitochondria or chloroplasts. When oxygen enters the mitochondria, it is processed there instead of in the host cell, turned by the mitochondria into water, with simultaneous production of adenos-

ine triphosphate (ATP) in large quantities. This procedure is known as respiration or oxidative phosphorylation.

However, reduction of oxygen does not happen at once, but requires several steps, with acceptance of one electron at a time. Correspondingly, electrons are not paired and are left alone several times. When the electrons do not pair, they become very unstable at the energy level, and as a result, the molecules become very violent, radically moving for pairing.

These molecules are so-called radicals. If this definition is applied broadly, halogens can also be regarded as radicals. In the oxygen reduction process (respiration), superoxide anions are produced in the first stage, peroxide is produced in the second stage, and hydroxyl radicals are produced in the third stage [8, 9], all of which are very rampant. In other words, when any element comes near these, the radicals wildly take electrons from the element. For example, if the subject is a microorganism, disinfection and sterilization occur immediately.

6. Endospore, not spore

What is this basic knowledge for? Spore is not a precise term. Instead, endospore is the appropriate word. Endospore is the decisive factor that distinguishes disinfection from sterilization, because sterilization must kill the endospore [3, 10].

Some gram-positive bacteria (*Bacillus* and *Clostridium*) can only make endospores, while gram-negative bacteria cannot. The differences between endospore and spore are as follows: a spore is a descendant generated by sex. Examples include conidia of *Aspergillus* and sporozoites produced in mosquitoes by *Plasmodium* male and female gametocytes. On the other hand, sex is irrelevant to endospores. They can be imagined as wearing a large number of thick coats and waiting for the day of reactivation when the bacteria are in a suitable environment. Endospores consist of bacterial DNA, some proteins and ribosomes for use in later reactivation, and dipicolonic acid (DPA). They have a thick protective wall with an inner membrane, and very sturdy peptidoglycan forms a spore wall and cortex. A thick coat surrounds the outer membrane. Therefore, the endospore can tolerate any insult, and even with insults, it can survive for hundreds of years. Endospores are also resistant to heat, but temperatures above 100°C can kill them. The process of reactivation is germination, and once exposed to water, the endospore swells and all protective walls burst. The result is the release of the same bacteria that existed before the endospore was formed.

7. Spaulding's classification

Spaulding's classification was proposed by Earle H. Spaulding in 1939, and it is the guideline that should determine the disinfection or sterilization method that should be chosen according to the medical instrument [11].

Instruments that touch intact skin are non-critical items. Fomites are good examples of such items. These must be sterilized unconditionally.

Instruments that contact incised skin or mucous membranes are semi-critical items. Examples include endoscopes and anesthesia equipment. These should undergo high-level disinfection.

Instruments that touch places where no single microorganism should exist are critical items. A representative example is a surgical instrument. These require low-level disinfection.

Classification and mechanism of disinfection and sterilization

1. Mechanism of disinfection

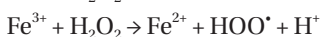
Disinfectants can be broadly categorized into oxidizing agents and non-oxidizing agents [12]. The former can be mainly seen as destroyers, while the latter are viewed as coagulators.

1) Oxidizing agents

Oxidizing agents include halogen agents such as sodium hypochlorite and iodine, as well as peroxide. The mechanisms of these agents in microorganisms are as follows:

(1) Action on DNA and RNA

When hydrogen peroxide takes one electron, hydroxyl radicals are formed. This situation is further promoted, especially if the iron in the body intervenes, in what is called the Fenton reaction [12].



These radicals break DNA or RNA strands directly or attack the phosphate backbone of purines or pyrimidines and ribose or deoxyribose. For example, when thymine is attacked by a hydroxyl radical, it becomes a thymine glycol [13].

The thymine glycol can be simply described as a broken thymine. The broken thymine cannot perform its tasks, such as replication, transcription, and translation as a nucleic acid. It also attacks the sugar (deoxyribose) of the DNA, thereby forming deoxyribonolactone and breaking the base.

(2) Action on proteins or amino acids

When oxidizing agents act on a peptide bond and take an electron, the bond breaks. As a result, the structure is deformed and therefore cannot function normally. This is fatal when an enzyme is damaged, in particular. Proteins or amino acids are also destroyed.

(3) Action on lipids

Oxidizing agents break down lipids into smaller fatty acids [13]. In particular, to take more electrons, they attack double bonds. In other words, unsaturated fatty acids are a preferred target. As a result, cells are damaged, and peroxidation of lipids creates other radicals, making the situation worse. When cell wall and membrane flexibility is lost and these stiffen, the cell eventually collapses and the contents burst.

2) Non-oxidizing agents or coagulating agents

Non-oxidizing agents or coagulating agents include alcohol, biguanides (chlorhexidine), quaternary ammonium compounds, phenol, aldehyde (glutaraldehyde), and ethylene oxide [3-7, 13].

A summary of the mechanism of non-oxidizing agents entails reacting with microorganisms and cross-linking all the ingredients to coagulate.

(1) Action on DNA and RNA

This action is especially prominent in alkylating agents such as ethylene oxide. Alkylating agents act on DNA or RNA molecules and cross-link the base structures. Moreover, these agents cross-link the structures to adjacent nucleotide bases, resulting in a disordered state. Thus, DNA strands do not undergo proper separation, which is the first step in DNA replication, and both replication and transcription are ultimately blocked [13]. In addition, if the DNA structure is erroneous, the DNA strand is destroyed by an automatic repair mechanism.

(2) Action on proteins or amino acids

Aldehydes are the main actors with this mechanism. When an aldehyde reaches the cell surface, it cross-links all amino acids or proteins [13]. Aldehydes particularly prefer lysine, asparagine, glutamine, and arginine, all of which have an amine group (-NH₂). As a result, the protein structure is destroyed, while the nucleic acids and lipid structures are swept together.

2. Mechanism of sterilization

Representative sterilization methods include the autoclave, which operates under the same principle as a pressure cooker,

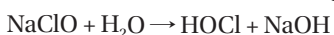
vapor, and hydrogen peroxide plasma or gas, which can be performed under non-high temperature conditions [14]. Other methods include chemical sterilants, which are disinfectants but have sterilization ability through control of the concentration and exposure time.

Disinfectants

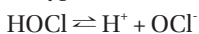
1. Oxidizing agents

1) Sodium hypochlorite (NaClO)

Sodium hypochlorite is an oxidant that has the structure NaClO (Fig. 1A) and is mainly used as bleach [15, 16]. At concentrations over 40% (> 500 ppm), it can corrode metals. Sodium hypochlorite should be carefully handled due to its irritation to the mucous membranes, and thorough rinsing should be performed after use. It must be mixed with water for use. Mixing sodium hypochlorite with disinfectants other than water can be dangerous. Using it with hydrogen peroxide in an enclosed space can lead to explosions due to the filling of the space with oxygen. Mixing it with acidic agents can result in the formation of chlorine gas, which leads to suffocation. When mixed with water, it undergoes the following reaction:



Hypochlorous acid (HOCl) is decomposed into acid (H^+) and hypochlorite (OCl^-), resulting in equilibrium.



Thus, hypochlorous acid and hypochlorite attack bacterial cell walls and the capsid of viruses to cause protein denaturation [13, 17].

Sodium hypochlorite does not kill spores at routine concentrations, but it has a sporicidal effect at 5,000 ppm or higher concentrations. For 5% sodium hypochlorite products, the concentration is 50,000 ppm. To achieve 5,000 ppm, 5,000/50,000 = 1/10.

Therefore, when 1 mL of sodium hypochlorite is mixed with 10 mL of water, 5,000 ppm can be obtained. Since the volume

of one lid is 10 mL, sodium chlorite crude liquid is poured into the lid and then added to 1 L of water, with the procedures repeated ten times. For reference, fruit and vegetables are sterilized at 100 ppm for five minutes, tableware is sterilized at 200 ppm, and general floor cleaning is sterilized at 400 ppm.

2) Povidone-iodine

The official name for what is commonly called povidone is povidone-iodine (polyvinylpyrrolidone Iodine) [18]. The reason for this terminology is that the iodine is placed in a chemical container called polyvinylpyrrolidone (povidone), and the iodine is slowly released (Fig. 1B). When iodine reaches a cell, it iodinate the lipids that are the main component of the cell membrane and oxidizes various cellular components. Therefore, use of products such as iodine tincture (iodine mixed with alcohol and water) that are applied at one time is effective for sterilization, but harmful to the human body. Povidone-iodine, on the other hand, can minimize toxicity by slowly releasing iodine [19, 20]. The reason to leave povidone-iodine sufficient time to dry after application (30 seconds to 2 minute) is because iodine requires adequate time to be released, penetrate the bacterial cell walls, oxidize the ingredients, and dominate the cells.

3) Hydrogen peroxide

Hydrogen peroxide (H_2O_2) does not kill spores effectively at a low concentration (< 2%) (low-level disinfectant), but it acts as a high-level disinfectant or chemical sterilant if allowed sufficient time at a high concentration (7.5–30%) [14, 21, 22].

H_2O_2 has a very unstable structure that can be broken at any time (Fig. 1C). Once the bond is broken via the Fenton reaction, as described above, a hydroxyl radical ($\cdot\text{OH}$) is formed, and it performs sterilization. Improved hydrogen peroxide is produced through mixture with surfactants, and this functions as a high-level disinfectant that can remove endospores and non-enveloped viruses if used for 5 minutes in 2% solution.

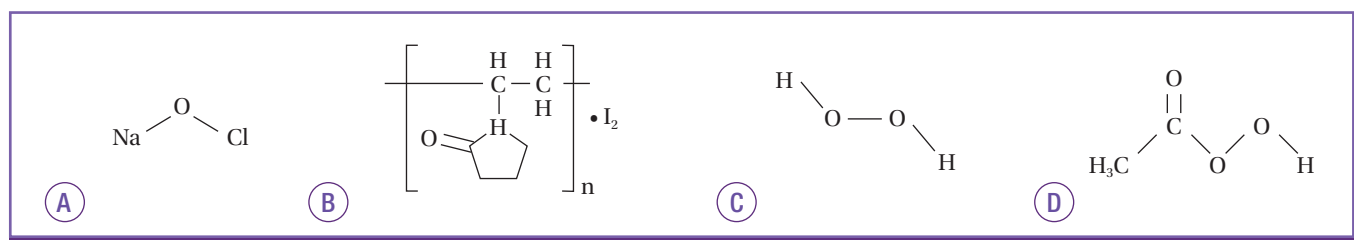


Figure 1. Structure of oxidizing agents. (A) Sodium hypochlorite; (B) Povidone-iodine; (C) Hydrogen peroxide; (D) Peracetic acid.

4) Peracetic acid

Peracetic acid has a structure of $\text{CH}_3\text{CO}_3\text{H}$ (Fig. 1D). It reaches the surface of a bacterium and destroys it by oxidation. At the same time, it also produces hydroxyl radicals and strengthens the sterilization action, especially in the destruction of sulfhydryl (-SH) and sulfur (S-S) bonds [13]. Peracetic acid is also effective in removing organic substances by breaking down the proteins. In other words, it can destroy biofilms. Even at low temperatures, it can kill endospores (chemical sterilization). It can corrode metals, so the peracetic acid disinfectant Scotelin includes a mixture of hydrogen, isopropanol, and anti-corrosive agents. It is used for disinfection of endoscopes and silicones [23-25].

2. Non-oxidant (coagulant)

1) Alcohol (ethanol)

The chemical formula of ethanol is $\text{C}_2\text{H}_5\text{OH}$ (Fig. 2A). It is used as an antiseptic at 60–80% concentration.

The reason it cannot be used at 80% or higher concentration is because the coagulation of the bacterial cell wall is excessive and the disinfectant cannot enter the cell. Because of its ability to evaporate water, an alcohol solution of 100% is harmful to skin. Therefore, ethanol is mainly supplied in gel form for hand moisturization and protection. The reason for its gel form is to prolong the contact time of microorganisms with alcohol by slowing the evaporation to further increase the sterilization effect. At a concentration of 70%, ethanol has anti-mycobacterial activity.

The basic mechanism of ethanol is denaturation and coagulation of proteins [13]. The hydroxyl group (-OH), which is the basic structure of alcohols, binds to microbial proteins via hydrogen bonding and damages protein structure and function, resulting in enzyme inhibition and protein deposition. It is not sporicidal but has sporistatic activity.

2) Chlorhexidine

Chlorhexidine (CHX) is a chemical produced from biguanide (two guanidines). If chlorine is added to bisbiguanide (two bonded biguanides), chlorhexidine is formed (Fig. 2B).

Chlorhexidine (CHX) becomes CHX salts, CHX cations with a positive charge, at physiological pH (*i.e.*, within the human body). Because of its positive charge, chlorhexidine binds well to the cell wall and membrane of negatively charged bacteria [13]. This binding results in cracks in the bacterial cells, causing the contents to leak and eventually causing the bacteria to burst. It strongly binds to the cells due to negative and positive

charge bonding, so it remains in place for a long time. Thus, unlike alcohol with its rapid action, chlorhexidine has a long-lasting effect [3, 26, 27].

3) Quaternary ammonium compound (QAC)

Quaternary ammonium compounds (QACs) have a positively charged chemically stable structure with four acyls attached to ammonium (Fig. 2C). They bind to the cell wall or cell membrane of bacteria and cause leakage, thereby disrupting the membrane potential and pH gradient of the cell. QACs also act as a cationic detergent. A representative example is benzalkonium chloride. QACs cannot kill endospores, *Mycobacterium*, and non-enveloped viruses (*e.g.*, norovirus). They are used for disinfection of non-critical items [3-7]. As an exception, norovirus can be inactivated with QAC 200 ppm or higher concentration or 2,470 ppm + alcohol [17]. Nevertheless, in the case of norovirus, it is good to use accelerated hydrogen peroxide or chlorine disinfectants. Bacteria resist QACs by treating them like fluoroquinolones or tetracycline. For example, bacteria expel QACs with an active efflux pump made up of *qac* genes mediated by a plasmid [28, 29].

4) Glutaraldehyde and ortho-phthalaldehyde (OPA)

Glutaraldehyde (glutaric acid dialdehyde) is formed by the bonding of glutaric acid with two aldehydes (Fig. 2D). It is usually in a very unstable state, and therefore shuttles hydrogen within itself, thereby becoming a ketone or enol (keto-enol tautomerization). When glutaraldehyde reacts with water, a hydroxyl group (-OH) attaches to it, thereby forming a hydrate. If the surrounding environment becomes alkaline, it can release hydrogen at any time. In other words, when this solution is alkalinized (precisely when there is a change from pH 7.5 to 8.5), it becomes a strong acid. Thus, it acts as a high-level disinfectant and sporicidal chemical (chemical sterilant) because of its ability to kill endospores [13]. It also had the advantage of not corroding endoscopes, thermometers, rubbers, and plastics. Glutaraldehyde kills mycobacteria well [30], but it is not very effective in killing some non-tuberculous *Mycobacteria* (NTM; *e.g.*, *M. chelonae*, *M. xenopi*, or *M. massiliense*). The long stretch of glutaraldehyde causes auto-cross-linking, and some molecules collide with each other, thereby disrupting penetration into the cell wall (steric hindrance). Glutaraldehyde may damage mucosa, so there is a risk of enteritis after colonoscopy or a risk of inflammation or damage to the cornea after use of ophthalmic instruments. Therefore, sufficient rinsing should be performed after use.

In ortho-phthalaldehyde (OPA; benzene-1, 2-dicarbalde-

hyde), two aldehydes are attached to benzene (Fig. 2E). That is, glutaraldehyde is made into a ring shape. Because of this ring shape, steric hindrance is less likely to occur than with glutaraldehyde, making it easier for the compound to penetrate into cells [13, 31]. Therefore, it kills NTM more effectively. There is a side effect of gray colorization if it is used for a long time, and there is a risk of anaphylaxis with cystoscopy. Therefore, OPA should be used with caution.

Sterilization

Sterilization is the complete elimination or destruction of all forms of microbial life. The most obvious form of sterilization is incineration. However, incineration is not practical because there are many instruments in the medical field that must be recycled. Therefore, the second best option is use of the autoclave [32].

1. Autoclave

The etymology of autoclave is auto (self) and clave (closing with a clanking sound).

To understand the autoclave, the concepts of vaporization pressure and boiling point should be comprehended first: If liquid is placed in a container in an enclosed space, it is evap-

orated and then returns, thus repeating condensation into water. Then, evaporation and condensation reach dynamic equilibrium. At this point, the pressure inside at which vapor is formed is the vapor pressure. When heat is applied to water, the temperature rises, the vapor pressure rises, and then the vapor pressure becomes equal to the atmospheric pressure. At that moment, the water surface evaporates, and vaporization occurs inside the water. The temperature at this moment is called the boiling point, at which the atmospheric pressure and the vapor pressure of the liquid are the same.

At normal atmospheric pressure (760 mmHg), boiling temperature is 100°C. However, the temperature must exceed 100°C to kill endospores. To overcome this, the boiling point should be increased by artificially increasing the pressure. This is the principle of the autoclave. By increasing the pressure, the autoclave reaches a boiling point of 100°C or higher (121°C) and kills endospores. *Geobacillus stearothermophilus* is used as an indicator to confirm whether sterilization has successfully occurred [33]. The autoclave is mainly used for glass, surgical instruments, and pre-treatment of wastes [14]. Of course, it cannot be used for heat-labile instruments (e.g., plastic, rubber, etc.), and other methods are performed for low temperature sterilization (e.g., ethylene oxide, hydrogen peroxide vapor or plasma).

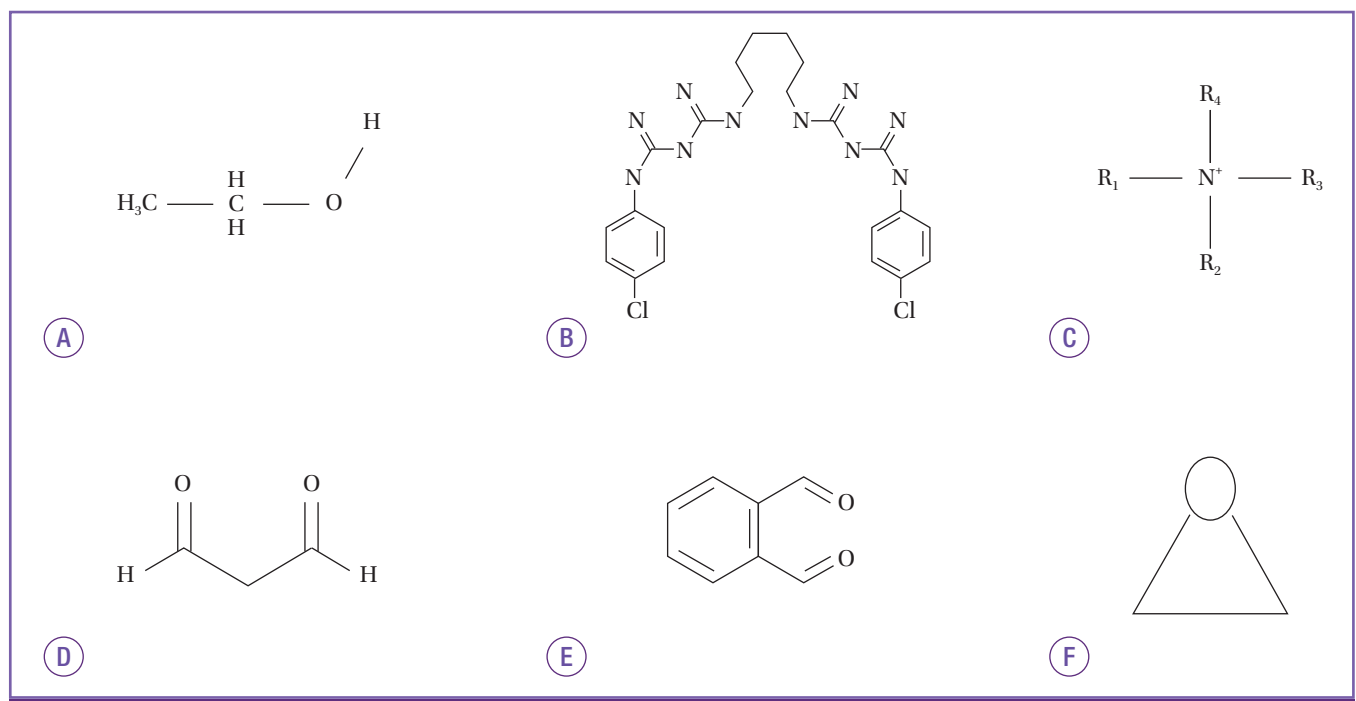


Figure 2. Structure of non-oxidizing agents (coagulants). (A) Ethanol; (B) Chlorhexidine; (C) Quaternary ammonium compound; (D) Glutaraldehyde; (E) Ortho-phthalaldehyde; (F) Ethylene oxide.

2. Ethylene oxide

Ethylene oxide is a cyclic ether, with a three-membered ring, like a snowman (Fig. 2F). As it is formed in an equilateral triangle shape around the oxygen, the two opposing sides of the triangle strongly pull against each other. Therefore, when provided an opportunity to react, it reacts more strongly than the other ethers. Ethylene oxide is used for sterilization of critical items such as plastics, which cannot withstand high temperatures [14].

Owing to its nature as a gas, ethylene oxide penetrates well into the cell, reaching the DNA of the microorganism and killing it by alkylation. It should be carefully handled because it may explode easily, and it should usually be maintained frozen. In terms of disadvantages, ethylene oxide can be harmful to the human body, and adequate time should be allowed for its function (6–12 hours). It is also a pollutant to the ecosystem [13, 14, 34, 35].

3. Hydrogen peroxide vapor or plasma

Plasma is the fourth phase of matter, comprising substances that are not in the water, solid, or gas state. It is produced by the application of microwave energy to hydrogen peroxide gas molecules. Hydrogen peroxide plasma contains numerous anions, cations, and hydroxyl and hydroperoxyl radicals. It penetrates the instruments well and sterilizes them. Unlike ethylene oxide, it can complete sterilization within a short time (about 50 minutes) and does not leave any toxic residue [34, 36]. However, it is expensive.

Conclusion

The decision regarding the choice of disinfection or sterilization should first be based on Spaulding's classification. Particularly in the case of a critical item, a method that kills spores should be selected, *i.e.*, sterilization. In addition, when disinfecting *Mycobacterium* species or non-enveloped viruses, the appropriate disinfectant (or chemical sterilant) must be selected prudently and correctly. The key to disinfection and sterilization is choosing the appropriate method for the appropriate indication.

Conflicts of interest

No conflicts of interest.

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