

Low Temperature Sterilization Technologies Past, Present and Future

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Abstract

The degrading of reusable invasive medical instruments, made of materials that could not withstand high temperature and pressure for a certain period of time during frequent sterilization cycles, could be overcome by using low temperature sterilization.

In this paper we have categorised medical devices, defined sterilization according to different standards, presented the available different techniques used to implement low temperature sterilization (like Ethylene Oxide(ETO), Formaldehyde(LTSF), Plasma, Peracetic Acid).

After comparison, it was found out that new technologies, like Plasma sterilization, have shown promising features (like short - cycled time, compatibility with most of the very expensive G.I. endoscopes, environmental friendliness), although certain drawbacks could limit the wide spread use of their application (for e.g: certain materials could not be sterilized using such a system, but it requires special consumables..). Generally however, these could be points of development for such technologies. Meanwhile, if disposable surgical instruments are proven to be economically feasible then this could be the right solution.

Introduction:

According to the risk of infection during their use medical devices could be grouped as follows: (Favero, M.S. 1991)

- 1- Devices that penetrate skin during use (e.g. Surgical instruments) Should be sterilized between uses.
- 2- Devices that touch mucous membrane during use (e.g. flexible endoscopes and anesthesia breathing circuits) should be either sterilized or, at least receive a high level of disinfection.
- 3- Devices that only touch intact skin (e.g. blood pressure cuffs and stethoscope) should be disinfected with intermediate or low level germicide or simply cleaned with soap and water, depending on the degree of contamination.

These items could either penetrate the skin or touch the mucous membrane, especially those made of materials not able to withstand autoclaving, since a rise in temperature to the range of 120 deg. C would damage or degrade their materials. The alternative is to apply a low-temperature sterilization process where temperature would not go beyond 70 deg. C..

Low-temperature sterilization methods are achievable by either gas (Ethylene Oxide, Formaldehyde), or plasma sterilization, or in the case of a high level disinfection, by immersion of instruments in chemical disinfectants for a certain period of time.

This paper focuses in more details on the main characteristics of each technology.

Low Temperature Sterilization: Equipment and Technique

Formaldehyde sterilizers had two different categories either combined gas and steam, or complete formaldehyde gas one.

Steiger et al (1994), could not perform sterilization w/ formaldehyde -Gas sterilization with temperature lower than 60 deg C, since sensitive material could be degraded under 50 deg C with an extended holding time.

Hurrell D.J. (1987) addressed the main problems of the low temperature steam and formaldehyde (LTSF) sterilizers, these problems were formaldehyde condensation on the chamber wall, and the non-uniformity of the gas steam mixture in the chamber. He suggested therefore, that solutions are as follows:

- 1- Maintaining the jacket at the same temperature of the chamber wall, would eliminate the formaldehyde

condensation on the chamber wall.

- 2- The non-uniformity of the gas steam mixture in the chamber, since both gas and steam mix very poorly, was solved during sterilizing hold period, after initial air removal – stage, formalin was admitted through a vaporizer, and there was a delay of two minutes before steam was admitted. This delay was to allow the formaldehyde to diffuse throughout the chamber. Steam was then admitted to raise the temp. to 73 deg. C. and chamber promptly re-evacuated, this cycle was repeated many times.

The biological indicators, *B subtilis* var niger and *B Streatothermophiles* were tested against sterilization process (dry heat, steam, ETO, LTSF). The tests results showed that both ETO and LTSF are comparable.

Formaldehyde is not flammable or explosive, and therefore there is no need for the extensive precautions. Although it is toxic, it is a known mutagen and is suspected of being carcinogen.

Formaldehyde odour is detectable at concentration of 10 P.P.M.

There is a number of devices which can not be processed through LTSF machines, either because they will withstand temperature at 75 deg. C. or because they can not withstand pressure variation.

Calbo, F., (1997), emphasizes the fact that using Ethylene Oxide sterilizers with an 88/12 ratio and freon gas has been stopped recently after the European Economic Community issued a directive calling for Freon to be replaced. The cycle was composed of Ethylene 88 and freon 12. The European Community requested the replacement of Freon with Tetrafluorochloroethane in order to protect the ozone layer. Now the use of a mixture 8.6% of Ethylene Oxide and 91.4% of inert gas which is HCPC-124 is common.

Vesley, D. et al, (1992) stressed that Ethylene Oxide (ETO) gas sterilization is highly effective against all types of microorganisms. It is readily available, non-corrosive, and able to penetrate all portions of the bronchoscope. However, ETO venting cap must be placed at the proximal end of the umbilical cable, which equalizes the pressure between the exterior and interior of the scope.

Failure to use the ETO venting cap will rupture the outer polyurethane sheath.

The disadvantage of ETO sterilization is the lengthy turnover time. ETO sterilization requires 4 hours followed by 12 to 24 hours of degassing time. This disadvantage makes it impractical. The other disadvantage is the ETO residue levels even after 12.5 hours of degassing time.

Plasma sterilization was introduced as an alternative of Ethylene Oxide sterilization it can be produced (Jacobs P.T., 1997) by a strong electric field, similar to neon lights. Aqueous hydrogen peroxide surrounds the items to be sterilized. When the field is created electrons are stripped from some of the atoms, and the resulting charged particles are accelerated. As the stripped electrons recombine with atoms, or as the electrons return from higher to lower energy states in activated atoms, a visible glow is produced. Molecular collisions also occur in the cloud, and the hydrogen peroxide is converted into a variety of other species, including for example, hydroperoxy and hydroxyl free radicals, water and oxygen. The reactive species in the plasma recombine to form primarily oxygen and water as by-products, eliminating the need for aeration. This technology is not designed to be used with cellulose-based products, lumen with a diameter of less than 6mm and length more than 31 cm. The equipment requires special biological indicators, trays, and wrapping papers, all should be compatible with it.

Plasma sterilization has many requirements (Calbo, F., 1997) like thermolabile, it must be completely clean and dry. No organic material, blood residue, salt residue, or sodium chloride must be left, and items must be first cleaned with desalinated water. Instruments with closed ends are excluded, as are highly absorbent materials and materials containing cellulose, thread cloth, or liquid, rust-prone materials are excluded, as are latex-rubber materials after three cycles or materials after just one use.

The study monitored 1000 sterilization cycles of the STERRAD system from November. 1994 to April 1995. Sixty one cycles were theoretically incorrect and voided by the microprocessor, these were divided into the following categories:

- 44% of these were cancelled due to the presence of moisture in some corrugated tubing.
- 26% due to the presence of paper containing cellulose.
- 25% due to cloth textiles.
- 5% due to the presence of wood.

Cycle time averaged 75 minutes.

The investigation of the relative efficacy of the hydrogen peroxide phase compared with that of the plasma phase, were based on (Kerbs, M.C. 1998):

- The antimicrobial efficacy of the peroxide and plasma

phases of the STERRAD 100 sterilization cycle.

- Secondary role was to compare B. Stearothermophilus and B. Pumilus for suitability as biological indicators for hydrogen peroxide processes.

The Results concluded that Hydrogen Peroxide in the STERRAD 100 cycle is extremely sporicidal and the STERRAD 100 Plasma phase appears to be non-sporicidal. No microbicidal effect was noted with increasing duration of exposure. It was possible to achieve high level of disinfection (Spauling, E.H 1968) 2% glutaraldehyde. Immersion for 10 minutes in 2% glutaraldehyde will destroy bacteria, viruses and 99.8% of mycobacterial organisms. Immersion for 45 minutes at 25 deg C. will eradicate all mycobacterial organisms. The disadvantages of disinfection by 2% glutaraldehyde include skin and eye irritation, need for adequate ventilation, disposal consideration (environmentally) because of its toxicity, and lack of means to monitor the necessary conditions (time, temperature, concentration). Other disinfectants such as phenol and isopropyl alcohol are less toxic, but their sporicidal actions are inferior compared to glutaraldehyde.

The increase in the use of heat and pressure-sensitive medical devices (Heeg, P. 1999) has tremendously intensified the need for sterilization processes which function at temperature below 70 deg C, while avoiding extreme pressures.

Because of the growing number of immuno compromised patients undergoing endoscopy (Spach, D.H. et al 1983) and the threat of transmission of pathogens between patients due to inadequately processed endoscopes, there has been a heightened awareness of the liability of infection in both public and medical communities. Cross contamination among patients undergoing endoscopic procedures has been reported. Ninety six infections were transmitted by the bronchoscope. Tuberculous mycobacteria and Pseudomonas species were the most commonly reported agents. Outbreaks of endoscopic related infections can be attributed to improper cleaning and processing procedures.

Steris developed a system (Steris System TM). The liquid chemical process is performed while controlled and monitored in a processor using a sterilant concentration Peracetic Acid (PAA) as the active biocidal agent.

Water is sterilized via a sterilizing grade filter located upstream in the fluid pathway. The sterilant is automatically mixed with sterile water to form a solution that flows into the chamber and comes in contact with all accessible external and internal surfaces of the instrument. The total time to process and sterile the bronchoscope is about 25 minutes.

Heeg, P. (1999) described the performance of Steris 20 which is usually filled with a sterilant concentrate that consists of 35 weights peracetic acid. The test

solution was automatically diluted in the processor to about 0.2% and has a PH of Approx. 6.4. The following test organisms were used in the experiments:

- *Staphylococcus aureus*.
- *Enterococcus faecium*.
- *Mycobacterium terrae*.
- *Pseudomonas aeruginosa*.
- *Candida albicans*.
- *Bacillus subtilis* spores (required by the US).

The processing temperature is 50-56 deg.C with sterilization time of 12 minutes. On conclusion of the sterilization cycle, the medical devices were rinsed 4 times with sterile-filtered water to ensure that all traces of the sterilization agent were removed. The total treatment cycle takes approximately 30 minutes. The potable water used is filterable through verifiable 0.2 micrometer. These are membrane filters that meet U.S. pharmacopoeia criteria of a sterilizing filter.

Each compartment and piping system of the devices were contaminated with 1 ml of a spore suspension of *B. Subtilis* (Organism count 10^9 / ml) by injection. The Material used for the tests:

- PTFE tubes 2 m length, 2 mm inner diameter and 1 mm.
- Rigid Endoscopy parts and accessories (selected items).
- Flexible endoscopes.

Results show that reduction of 6 log of *B. Subtilis* spores was achieved. In cases of remaining contamination, it was of a very low level and could be related to surface damage or handling difficulties. A careful pre-cleaning of the load and the carrying out of an effective disinfection will minimize the bioburden before the terminal process.

The medical products to be processed should be in good condition and free of damage such as corrosion or other material flaws. A fundamental question here arises as to whether the tested system is considered a sterilization process in Europe. Considerable definition difference still exists between the US and Europe regarding just in time sterilization processes.

Since in the US such process is considered as a sterilization process. In Europe Sterilization is defined as the removal of the germs within a package ensuring sterile conditions. Storage of the sterilized devices is not possible within the test system once the processor has been opened as it designed for just in time use.

Discussion and conclusion:

To summarize all previously mentioned sterilization technologies, table

.1. shows the main characteristics of each one of them.

Low temperature sterilization is very important in most health care facilities, When making a choice for the proper technology. This has to be treated case by case, but certain criteria have to be considered before proceeding into adopting any of the previously mentioned techniques. These are:

- 1- The capital devoted to those instruments which required such sterilization, and the frequency of their use.
- 2- Is there any endoscopy equipment going to be used? How many sets are there?
- 3- Although the American standard did not require sterilization process for flexible endoscopy equipment, the European did stress the fact since most of the endoscopy's procedures involve either cutting and treating bleeding wounds, in addition to direct contact to mucous so they would require sterilization.
- 4- How many operating theatres are there?
- 5- In case decision is made towards purchasing a gas sterilizer, would the hospital be prepared to devote a special remote area for such equipment?
- 6- Is the hospital ready to:
 - A) Dedicate staff for loading and unloading the equipment whenever it is required?
 - B) Bear the consequences of the hazardous residue on both humans and the atmosphere.

ETO sterilizers required very extended completion cycle in addition to the risk of its long term toxic effect on staff; also combined formaldehyde and steam sterilizers still have a long cycle and have a similar toxic effect on staff in the long run. Therefore, research has to focus on the new technologies (i.e. plasma sterilizers), since they have the potential of replacing the ETO, and LTSF's. scientific research is urgently required to prove their efficiency and to find out about other features. Meanwhile it is recommended to use until new technologies prove to be economically feasible alternatives.

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Table .1. Comparison table for the different low-temperature sterilization technology

	ETO	LTSF	Plasma	Steris	Immersion in Chemicals
Duration Of cycle	16-24 Hours	3-4 Hours	75 Minutes	12 to 30 min High level of disinfection while 6-10 hours in case of sterilization	45 Minutes
Number of cycles during 16 working hours	1	4	12-16	2-25 depending on whether it is high level disinfection or sterilization.	10-16
Agent for sterilization	ETO	Formaldehyde + steam	Hydrogen Peroxide	Paracetic Acid	Glutaraldehyde
Sterilization temperature (deg. C)	50	75	50	50-56	25
Is operation accompanied with odours	No	Yes	No	Yes	Yes
High frequency ventilation requirements	Yes	Yes	No	Yes	Yes
Level of detection	200 P.P.M	10 P.P.M	-	-	-
Effect on humans	Toxic, Carcinogen	Toxic, Carcinogen	Nothing proven negative.	-	Eye and skin irritation, Toxic
Consumables	Biological Indicators, wrapping paper, ETO canisters	Biological Indicators, wrapping paper, formalin canisters	Biological indicator, special trays, wrapping paper + hydrogen peroxide cassettes + boosters	Chemicals	Chemicals
Other limitation	Sometime ETO residue in items even after aeration	1-Purchasers have to ensure that equipment cycle were modified to avoid the : formaldehyde condensation and non-uniformity of the gas steam Mixture 2- some devices could not withstand the 75 deg C or the pressure variation	Sterilization could not be realized for equipment with closed ends, cellulose based, thread, cloth, liquids, rust prone materials, latex rubber materials after three cycles. Lumen w/ diameter of less than 6 mm and length more than 31 cm.	Instruments packaging is not possible, since the equipment is based on soaking them into the sterilization agent + water. This necessitates the use of instrument directly after the cycle end.	Special consideration in disposing the chemicals

References

1. Favero, M.S. (1991), *Infection Control and Hospital Equipment, Strategies for Disinfection and Sterilization of Endoscopes: The Gap between Basic Principles and Actual Practice*, Vol. 12 No. 5. PP: 279-281.
2. Steiger, K. & Steel.K. (1994), *Zentr. Steril. The Efficacy of Formaldehyde-Gas Sterilization at 50 C in Comparison with 60 C*, Vol 2.
3. Hurrel, D.J. (1987), *Low Temperature Steam and Formaldehyde Sterilization (LTSF): Its Effectiveness and Merits*, *Journal of Sterile Services Management*, June edition pp: 40-43.
4. Calbo, F., (1997), *Case Study, Low Temperature Gas Plasma Sterelization*, Johnson and Johnson Med. Inc. research publication.
5. Vesley, D, Norlien KG, Nelson B, Orr B, Streifel AJ. (1992), *Significant Factors in the Disinfection and Sterilization of Flexible Endoscope*, *Am. J. Infec. Control*, Vol .20. PP: 291-300.
6. Jacobs, P.T., (1997), *ETO Alternatives* , Johnson and Johnson Med. Inc. research publication.
7. Kerbs, M.C., Becasse P, Verjat D, Darbord J.C. (1998), “*Gas-Plasma Sterilization: Relative Efficacy of the Hydrogen Peroxide Phase Compared with That of the Plasma Phase*”, *International Journal of Pharmaceutics* Vol. 160. PP:75-81.
8. Spauling, E.H. (1968), *Chemical Disinfection of Medical and Surgical Materials*. In: Lawrence CA, Black SS, eds. *Disinfection, Sterelization and Preservation*. Philadelphia: Lee and Febiger PP:250-266.
9. Heeg, P. (1999), *Effectiveness Study of a Low Temperature Liquid Sterilization Process Using Peracetic Acid*. *Zentr. Steril*: 7(1), PP:18-29.
10. Spach, D.H., Silverstein, F.E. & Stamm,W.E. (1983), *Transmission of Infection by Gastrointestinal Endoscopy and Bronchoscopy*. *Ann Intern. Med.*; Vol. 118. PP: 117-128

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