Evolution of sterilization and recent advances in sterilization technology

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Background

The history of sterilization was separate from surgery in its early days. Surgery precedes sterilization long before sterilization principles being introduced in the 1800s.[1] The concept of sterilization as a statistical process is explained. Various modalities of conventional physical and chemical sterilization such as dry and moist heat, radiation, ethylene oxide, ozone, hydrogen peroxide, along with advanced methods being introduced recently, have been investigated. In health care setting sterilization processes can be divided into low-and high-temperature processes (LTS),(HTS).

Ancient times discoveries [1]

Discoveries were empirical and solely based on shrewd observations. Sterilization and decontamination originate in the concept of preservation and infection prevention.

Main discoveries [1]

- Drying
- Salt solutions (brines)
- Smoking
- Sugar (sucrose) solutions
- Passing surgical instruments through flame (Middle East)

- Low temperatures slow bacterial growth (Ice houses are recorded in Summarian writings from 4500 years ago)
- The combination of physical and chemical methods by ancient Egyptians (mumification)
- Healing effect of plant extracts and produces
- Keeping water in copper or silver vessels (450 BC)
- Greeks Hippocrates (460-370 BC): Boiled water & medicated dressings for wound treatment
- Egyptians (300 BC) Embalming and preserving
- Romans Galen (130-200 AD): Boiled instruments when treating wounded Roman gladiators [1]

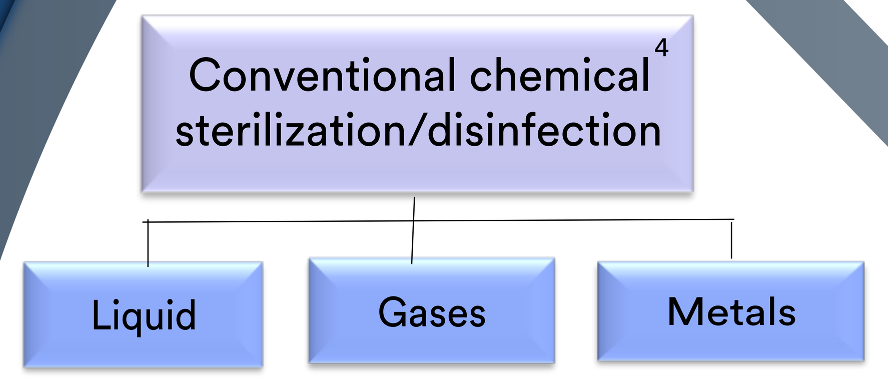

Figure 1 Conventional methods

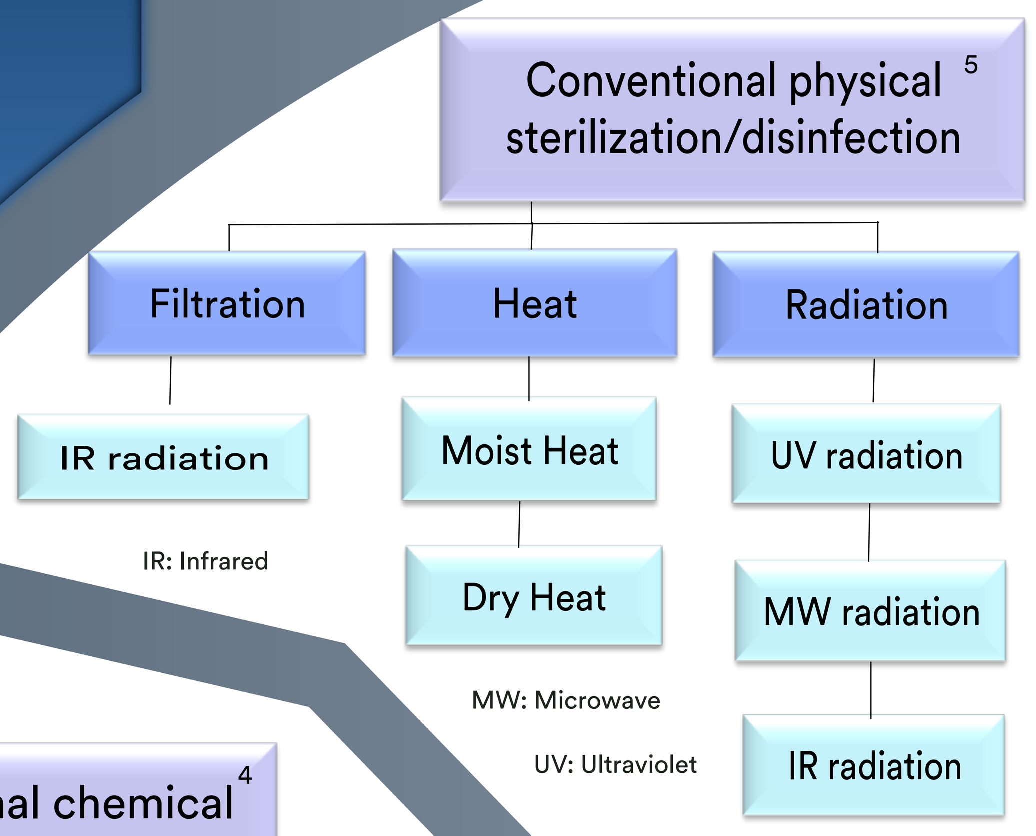

Figure 2 Conventional physical methods

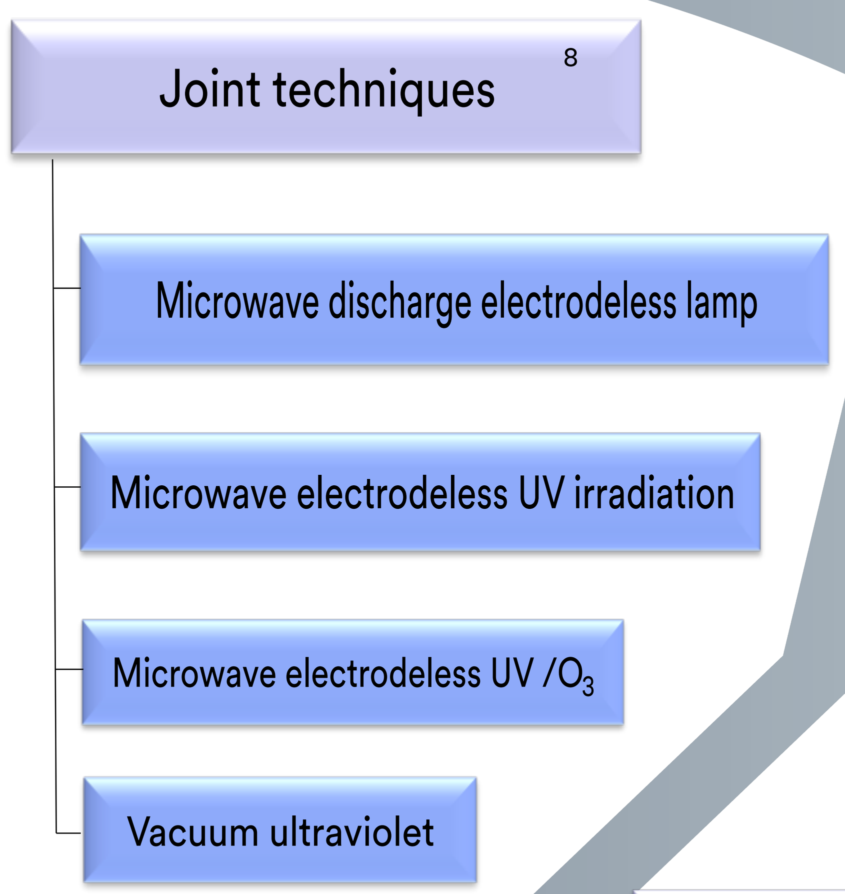

Figure 3 Joint techniques

Early applications of heat as a preservative: [2]

Nicholas Appert (1810) airtight food preservation (Appertization)
Louis Pasteur (1866) recommended heating new wine at 55°C in the absence of air.
This mild treatment, later known as pasteurization

The autoclave [2]

Denis Papin (1681) Digester or engine, Steam under pressure i.e. pressure cooker
William Henry (1831) "Experiments of the disinfecting power of increased temperature with the suggestion of a substitute for quarantine"
Pasteur (1876), **Koch and Wolffhuge** (1881)
Pasteur noted that moist heat was more effective than dry heat
Charles Chamberland (1884) developed the first pressure steam steriliser, or autoclave.

Sterilizer [2]

1883—Radial, locking-arm door on sterilizer
Steam tight, easy lock
1890—1st hospital steam sterilizer Rochester City Hospital
Sprague-Schulyer, Thermometer but no temp control, For dressings
1892—Hospital steam sterilizer at Roosevelt Hospital NYC
Sprague-Schulyer, With pressure gauges and thermometer, for water, dressing and instruments

Dry heat sterilization [6]

less complexity in operation, no requirement of pressure and vessels, exterior jacket not required, lighter in weight, and it has fewer requirements. However, it requires more time, and specified for certain materials.

Moist heat [6]

It is extensively used, it is nontoxic, inexpensive, sporicidal and rapidly microbicides, technology well advanced, however the elevated temperature and moisture, makes it not suitable for heat and moisture sensitive medical devices

Method

Literature review of traditional and advanced methods are reported along side with comparison of advantages & disadvantages of each group.

Ethylene oxide (EO) [10]

EO is one of the most prominent methods used for the industrial sterilization. Pure gas or mixed with a gas carrier is used for the sterilization process. It has the highest material compatibility, it is a LTS system, however, it is volatile and has along aeration time.

Vaporized hygrogen peroxide (VH2O2)[10]

H2O2 is also a LTS process, it has been used in hospitals mostly for sterilization of devices such as polyethylene & polytetrafluoroethylene reusable flexible endoscopes since 1993, however there are lumen inner diameter and lumen length limitations, not compatible with cellulose. Also there is weight limit.

Table 3 Recent techniques

	Principle involved	Parameters	Applications
Pulse light (PL)[7]	Use of intense pulses of short duration and the use of broad spectrum to confirm micorbial inactivation. During its working, electromagnetic energy is collected in a capacitor within a fraction of second and then free in the form of light within a short time	Intensity of light and number of pulses, product area, type of microorganism, viscosity, thickness, color, opacity, samples flow rate, presence of particulate material	Fresh keeping of fruits and vegetable, meat preservation, decontaminating the foodborne pathogens

Table 4 Recent techniques

	Principle involved	Parameters	Applications
Ultra-High Pressure [7]	Le Chatelier's principle Principle of microscopic ordering Isostatic principle	The inactivation of pathogens and spoilage of bacteria, viruses and spores depend upon pressure with or without heat	Application of pressure reduces the thermal exposure of the food during processing, thereby protecting a variety of bioactive compounds. Treatment of vegetable juice, milk, fruit, milks, and food component

Table 5 Recent techniques

	Principle involved	Parameters
Supercritical fluid[7]	Supercritical fluid,it depends on the pressure and temperature above critical point of the fluid under supercritical condition.	Temperature, pressure depressurization rate, pressure cycling, use additives, treatment time, density of CO_2, CO_2 flow rate

Table 6 Applications

Applications
Food, biomedical, and pharmaceutical application

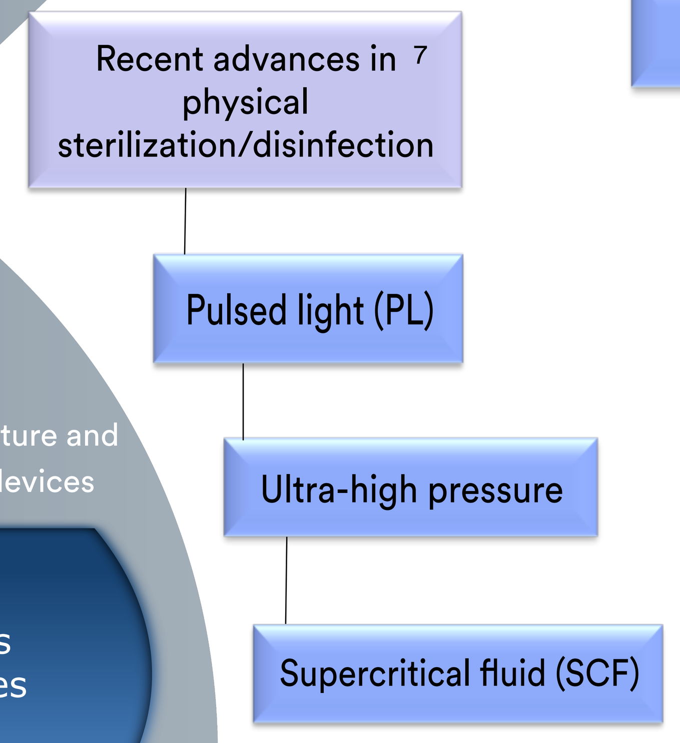

Figure 4 Recent advances in physical methods

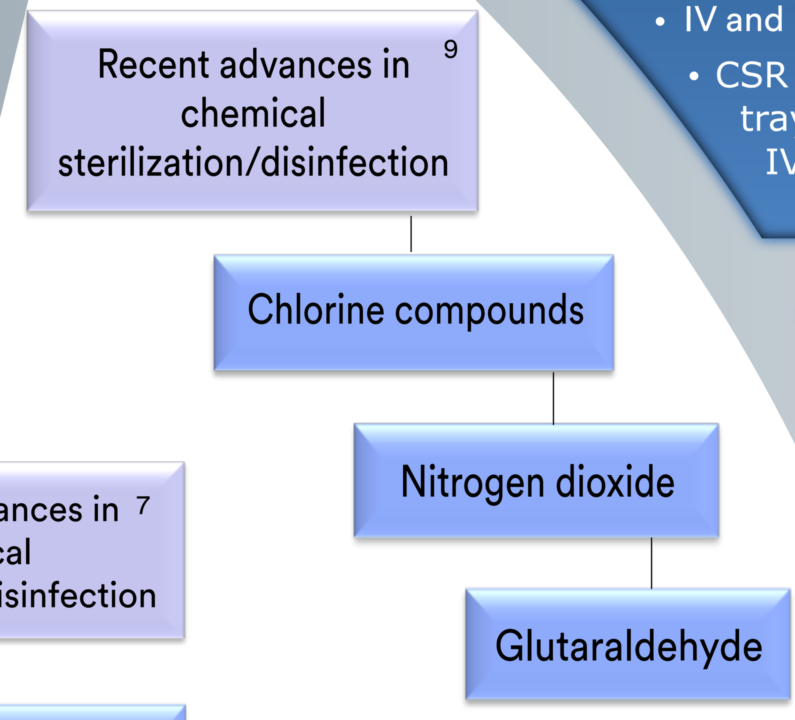

Figure 5 Recent advances in chemical methods

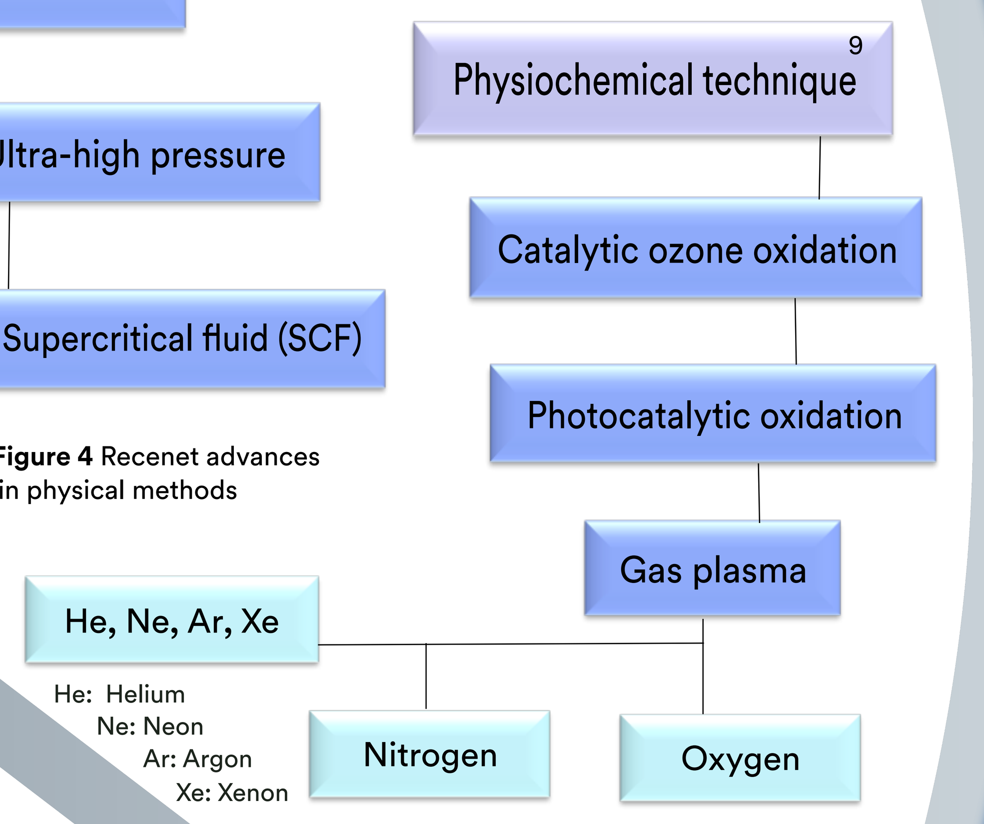

Figure 6 Physiochemical techniques

Table 1 Antiseptics, preservations, disinfectants and certain sterilization procedures [1,2,4]

	Date of introduction	Age at 2023
Tar	1716	307
Eau de Javel	1774	249
Bleaching powder	1789	234
Chlorine gas	1832	191
Iodine	1839	184
Chlorine water	1842	181
Phenol	1860	163
Formaldehyde	1886	137
Hydrogen peroxide	1887	136
Cresol/soap solution	1897	126
Chlorinated phenols	1906	117
Triphenylmethane dyes	1912	111
Flavine dyes	1913	110
N-chloro compounds	1916	107
Quaternary ammonium compounds	1917	106
Ethylene oxide	1936	87
Amidines	1942	81
Iodophor(e)s	1949	74
Chlorhexidine	1954	69
Peracetic acid	1955	68
Glutaraldehyde	1957	66
Appertization	1810	213

Table 2 Techniques

	Date of introduction	Age at 2023
Autoclaving	1880	143
Pasteurization	1886	137
Natural radiation	1896	127
X-rays	1898	125
Ultra-violet light	1903	120

Reprocessing area

Up to 1930s Reprocessing occurred in ORs
- Viewed as sterilization experts
- Largest users of sterile supplies
- Often produced sterile products for entire hospital

Sterilizers initially located in theatres
As ORs became busier, sterilizers relocated to OR workrooms, still supervised by OR nurses
- Earliest reference to central supply room (CSR)—1937 [3]
- Scope of CSR services varied, depending on the facility
- Surgical supplies—gowns, gloves ,needles, sutures, drapes
- All sterile supplies— forceps, rubber goods e.g. catheters, gloves
- Sterile treatment trays
- Blood collection and storage
- IV and irrigating solutions
- CSR nurse might accompany complex or emergency trays, and assist physician e.g. Gastric decompression, IV Therapy, spinal puncture

- 1950s— Ethylene Oxide sterilization in hospitals
- 1956—Principles and Methods of Sterilization by J.J. Perkins Set the current standards and methods for reprocessing medical devices
- 1959—Prevacuum air removal sterilizer
- 1963—Glutaraldehyde approved as a liquid chemical sterilant by EPA
- 1969—Pulsing vacuum air removal sys.
- 1987—Blood & body fluid precautions
- 1989—Liquid peracetic immersion
- 1993—Hydrogen Peroxide sterilizer [2]

Conclusion

Sterilization is an effective technique capable of destroying microorganisms to prevent disease transmission associated with the use of the affected medical device.
Research in this field is unique & covers many applications in different industries.
Several types of traditional (physical & chemical) techniques are mentioned.
These techniques have some drawbacks such as toxic by-products.
Advanced techniques being developed to overcome barriers of convectional methods such as time and not leaving hazardous residues behind, however they are still limited in terms of application and scalability.
Further studies need to be performed on these techniques in order to increase capabilities, scale and reduce the process cos so that they can compete with conventional systems.

References & Acknowledgements

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