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## Recent Advances and Emerging Trends in Operation Theatre Sterilization Techniques

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**Abstract:** Operating room (OT) sterilization and terminal disinfection procedures have changed significantly between 2015 and 2025. Vaporized and aerosolized hydrogen peroxide systems, ultraviolet (UV-C and pulsed xenon) whole-room devices, low-temperature plasma sterilization, peracetic acid fogging, automated ozone systems, sophisticated antimicrobial surface coatings and micro-patterning, and improved environmental control techniques (ventilation, filtration) are some of the innovations. Concurrently, industry and practice have changed due to stricter regulations and standards (ISO, AORN, ASHRAE, EPA) and growing worries about ethylene oxide emissions. This review identifies knowledge gaps and future prospects for research and clinical application, summarizes comparative performance and safety issues, and synthesizes the literature from 2015 to 2025. [1–6].

**Keywords:** Operating theatre, Sterilization, Hydrogen Peroxide Vapor, UV-C, Plasma Sterilization, Peracetic acid, Ozone, Antimicrobial coatings, Ventilation Standards

### Introduction

To avoid surgical site infections (SSIs) and healthcare-associated infections (HAIs), operating rooms must maintain the highest standards of asepsis. While environmental and whole-room decontamination technologies have advanced rapidly since 2015, traditional instrument sterilisation (steam autoclave, ethylene oxide for heat-sensitive objects, radiation) is still fundamental. The COVID-19 pandemic increased interest in strong ventilation tactics and automated, no-touch room disinfection techniques for airborne pathogen prevention. Developments and trends from 2015 to November 2025 are covered in this study. [1–5].

### Methods:

I conducted focused literature searches publications, standards (ISO, ASHRAE), organisational guidelines (CDC, WHO, AORN, FDA), and recent review articles and trials. Vaporised hydrogen peroxide (VHP/H<sub>2</sub>O<sub>2</sub>), aerosolised hydrogen peroxide (aHP), UV-C and pulsed xenon UV (PX-UV), low-temperature hydrogen peroxide gas plasma (HPGP), low-temperature plasma sterilisation, peracetic acid (PAA) fogging, ozone automated systems, antimicrobial coatings (copper, silver, nanoparticles, surface micro-patterning), ventilation/air filtration in OTs, biological/chemical indicators and monitoring, and regulatory changes (EtO/ethylene oxide). Systematic reviews, randomized/controlled studies, large observational trials, and authoritative guidelines were given priority in the review. (Detailed sources are provided below.)

### Key technologies and evidence

#### 2.1 Hydrogen peroxide that has been vaporised or aerosolised (VHP/aHP)

VHP and aerosolised H<sub>2</sub>O<sub>2</sub> systems have evolved from sterilising devices to decontaminating entire rooms. Large log

reductions of pathogens on surfaces and in the air are reported in numerous hospital studies and reviews, including better terminal cleaning results; some quasi-experimental and before-and-after studies showed decreased environmental bioburden and decreased transmission of specific MDROs when used as adjuncts to manual cleaning. Operationally, safety—staff exposure and room aeration times—remains crucial. [6–10].

#### 2.2 Pulsed xenon UV (PX-UV) and ultraviolet germicidal irradiation (UV-C)

As supplements to manual cleaning, UV-C and PX-UV "no-touch" devices have been extensively studied. Studies conducted in vitro and, in the environment, demonstrate a significant decrease in surface bioburden; when devices are used appropriately as supplements to cleaning procedures, certain clinical studies suggest decreases in HAIs (such as MRSA and *C. difficile*). However, systematic reviews warn about outcome heterogeneity and the necessity of appropriate placement/overlap for shadowed locations; more rigorous studies are required, according to recent meta-analyses. [11–16].

#### 2.3 Hydrogen peroxide gas plasma (HPGP) with low-temperature plasma sterilisation

Due to the environmental benefits and instrument compatibility (heat-sensitive devices), low-temperature plasma and HPGP have attracted increased attention. Strong microbicidal action for many pathogens is indicated by reviews and experimental work; however, organic load and chamber settings can affect effectiveness; ongoing research has concentrated on clinical validation and expanding plasma technology to whole-room or surface applications. [17–19].

#### 2.4 Fogging and aerosolised peracetic acid (PAA)

PAA aerosol systems, often known as fogging, have been shown

in controlled tests to be highly effective surface disinfectants. They are used to decontaminate rooms, however strict aeration/clearance procedures and monitoring are required because of concerns about respiratory exposure and material compatibility. Efficacy as a terminal disinfection adjuvant is supported by data from institutional research and public health applications (hospital wards, schools). [20–22].

### 2.5 Automated room disinfection using ozone

In laboratory and medical research, ozone with regulated humidity has shown efficacy against viruses (including SARS-CoV-2) and other infections. Ozone systems can be useful, but because of material compatibility and human toxicity, they need stringent safety regulations. According to recent assessments, ozone is a practical supplementary choice in situations where exposure is prevented by engineering safeguards. [23–25].

### 2.6 Antimicrobial coatings, surfaces, and micro-patterning (Sharklet, copper, silver, and nanoparticles)

Surface microbial burden is decreased by antimicrobial copper alloy surfaces, silver-based coatings, and newly developed nanoparticle and photocatalytic coatings. Although the quality of the evidence varies, certain clinical trials and systematic reviews point to potential reductions in HAIs as well as decreases in environmental contamination. An intriguing development to lessen biofilm growth without releasing biocides is the use of micro-patterned non-chemical surfaces, such as Sharklet. Research on durability, affordability, and long-term clinical efficacy is still ongoing. [26–31].

### 2.7 Changes in industrial practice and ethylene oxide (EtO)

Many heat-sensitive devices still require ethylene oxide, although worries about cancer risk and stricter EPA restrictions (2023–2024) have prompted industry adjustments and regulatory action, including pilot programs to lessen EtO reliance and evaluation of alternate sterilants. Supply chains for sterilisation are changing as a result of this regulatory pressure, and when feasible, alternative sterilants are being adopted. [32–34].

### 2.8 Airflow, ventilation, and HVAC techniques in OTs (including discussions of laminar flow)

System design standards (ASHRAE/ASHE Standard 170 and others) and ventilation (HEPA filtration, air changes per hour, positive pressure) continue to be crucial. Since 2015, research has reevaluated the benefits of laminar flow. A number of meta-analyses and reviews have found conflicting evidence that laminar flow alone lowers SSI when compared to well-designed turbulent systems, highlighting the need for ventilation to be combined with infection control bundles (door control, traffic, sterile technique). [35–40].

### 2.9 Biological and chemical markers, monitoring, and validation

For routine control and steriliser validation, robust process monitoring (biological indicators, chemical integrators, physical parameters) is still essential. Real-time assurance of sterilisation is being improved by more recent quick BI readouts and regular data integration into sterile processing procedures. [41–43]

## III. The impact of COVID-19 on OT sterilisation procedures

The COVID-19 pandemic (starting in 2020) accelerated the use of automated whole-room disinfection systems, increased the use of VHP and UV-C robots, and increased focus on ventilation and PPE decontamination. Reports detailed operational difficulties (turnover time, supply constraints, personnel training) as well as advantages (quick cleaning, decreased environmental persistence). Instead of replacing routine cleaning, many facilities used these technologies as supplements after the pandemic. [44–48].

## IV. Practical considerations, safety, and comparative efficacy

**Effectiveness:** For several infections, lab studies consistently demonstrate substantial log reductions for VHP, PAA, ozone (in controlled humidity), and UV-C/PX-UV; clinical translation reveals varying impact sizes for HAI reductions depending on baseline HAI rates and procedure adherence. [6,11,17,23].

**Safety and exposures:** Aeration times, engineering and administrative controls, and monitoring are necessary because of the occupational exposure concerns associated with H<sub>2</sub>O<sub>2</sub>, PAA, ozone, and EtO. Practical supply concerns result from regulatory attention to EtO emissions. [9, 20, 32].

**Operational:** Shadowing (for UV) and organic load (for oxidants) limit efficacy unless cleaning and device positioning are optimum; no-touch devices increase costs and lengthen room turnover times. Device usage and the HAI baseline determine the cost-benefit ratio. [11,17,23].

## V. Guidelines, rules, and standards (2015–2025)

The CDC's disinfection/sterilization guidelines, WHO COVID-era surface cleaning guidelines, AORN perioperative practice updates, ASHRAE/ASHE ventilation guidelines and Standard 170, ISO sterilisation standards (ISO 14937, ISO 11135 for EtO), and FDA and EPA regulatory actions regarding sterilant safety (particularly EtO emission limits) are some of the important guidance documents and standards that have been updated or emphasised during this time. Clinical acceptance has been largely dependent on adherence to standards and workplace safety guidelines. [1, 2, 32, 35]

## VII. Research priorities, gaps, and future directions

There are currently few high-quality clinical trials that compare whole-room disinfection systems side by side for HAI outcomes; the majority of these research use observational or surrogate (environmental bioburden) endpoints. [11, 17].

**Material compatibility and occupational safety:** a thorough assessment of the long-term impacts of repeated oxidant usage on OT materials and worker exposures is necessary. [20, 23]. Combining surface engineering (antimicrobial coatings), no-touch disinfection, ventilation techniques, and sterilisation procedures into affordable packages that clearly lower SSIs. [35–37].

**Alternatives to EtO:** Scalable substitutes for complex device sterilisation must be developed and validated due to regulatory pressures on EtO. [32–34].

Axios

IoT-enabled steriliser logs, quick BIs, and environmental sensors

for real-time compliance and assurance are examples of data-driven monitoring. [41–43].

## VII. Conclusion

Adjunctive automated whole-room systems (VHP, aHP, UV-C/PX-UV), oxidant fogging (PAA, ozone), low-temperature plasma alternatives, antimicrobial surface technology, and enhanced ventilation standards are all examples of how the operating room sterilisation landscape has evolved. Although several modalities have excellent laboratory efficacy, there is conflicting clinical evidence regarding HAI reduction, and implementation issues (cost, turnover time, safety) still exist. Pragmatic trials, interoperable monitoring, cautious occupational protections, and standard-aligned strategic adoption are all necessary for future advancement. [1–6,11,17,32,35]

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