Safety inside the Operating Room – an overview of the factors influencing a Healthy Surgical Microenvironment

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SUMMARY
This review addresses the surgical microenvironment - the air surrounding the operating site bounded by the patient, surgical team, and equipment - and its role in patient safety. A safe microenvironment minimises surgical site infection risk from airborne microorganisms and reduces intraoperative hypothermia. Building on research on operating room ventilation, this review synthesises current literature to examine how ventilation strategies and local factors influence air quality near the surgical field. Particular attention is given to unidirectional and turbulent airflow systems, as well as the role of surgical clothing in thermal comfort. The effects of staff posture and movement, thermal plumes, patient warming, and surgical equipment on ventilation effectiveness are also examined.

KEYWORDS
Operating room, Surgical microenvironment, Ventilation system efficacy, Patient safety.

1 INTRODUCTION
Nowadays, surgical site infections (SSIs) remain prevalent at 2.5% (Mengistu et al., 2023), highlighting the need to identify the operating room (OR) zone most critical to patient safety: the surgical microenvironment, the area immediately bounded by the patient, surgical team, and surgical lights (Woods et al., 1985). Its air quality prevents airborne microorganism contamination, and thermal conditions avoid intraoperative hypothermia (Sadeghian et al., 2022), both linked to adverse postoperative outcomes. However, its protective level depends on interactions between ventilation airflow, OR-specific room characteristics, and surgeons' thermal comfort.

2 METHODS
A literature search was conducted in Scopus, Web of Science, Taylor & Francis Online, and Springer Nature Link using Boolean keyword combinations aligned with the study scope. After removing duplicates and screening for relevance, 41 articles were retained for analysis.

3 RESULTS
The most commonly installed ventilation systems in ORs are Turbulent Airflow (TAF) and Unidirectional Downward Airflow (UDAF) systems. Table 1 summarises the diverse ventilation and environmental requirements mandated by key national guidelines. Their protective efficacy is governed by interaction with the surgical microenvironment. Surgical lamps disrupt UDAF by generating low-velocity wakes, reducing local air velocity to ≤0.02 m/s (Aganovic et al., 2017). Surgeons' bent postures obstruct airflow and create a low-pressure vorticity zone, increasing particle trapping, while door opening and staff movement generate turbulent wakes that transport contaminated air towards the operating table (Li et al., 2020; Liu et al., 2024). Convective flows from surgeons and patient warming systems challenge airflow penetration, requiring UDAF supply velocities above 0.3 m/s and increasing contamination risk when poorly controlled (Tacutu et al., 2022; Sadeghian et al., 2022).

Table 1. International OR ventilation standards requirements (n.r. = not reported).

Guideline	Supply Volumetric Airflow Rate, $V_{total}\|_{in}$ [m^3/h]	Air Change Rate, ACH [h^{-1}]	Mean Air Dry Bulb Temperature, $T_{db,ha}\|_{out}$ [°C]	Relative Humidity, $\phi_{ha}\|_{out}$ [%]
Portugal: ET 06/2008	≥ 600 or 100 m^3/(h·person)	≥ 5	[17 ; 27]	[30 ; 60]
United Kingdom: Health Technical Memorandum 03-01: Specialised ventilation for healthcare premises	10 L/(s·person) Notes: ▪At least 20% of fresh air when recirculated air exists.	≥ 22	20 (summer) 22 (winter)	[35; 60]
Nordic: R^3 Nordic Guideline for Hospital Ventilation	≥ 990	n.r.	[18 ; 26]	< 60 (at 21 °C)
Germany: DIN 1946-4: Ventilation and air conditioning – Part 4: Ventilation in buildings and rooms of health care	For TAF: ≥ 60 m^3/(h·m$^2\|_{operating\ area}$) For UDAF: ≥ 900 m^3/(h·m$^2\|_{supply\ diffuser\ area}$) Notes: ▪At least 1200 m^3/h of fresh air.	For TAF: ≥ 20 For UDAF: n.r.	[19 ; 26]	[30; 65]
Spain: UNE 100713	≥ 2400 Notes: ▪At least 1200 m^3/h of fresh air when recirculated air exists.	≥ 20	[22 ; 26]	[45; 55]
United States: ASHRAE 170-2021: Ventilation of Health Care Facilities	n.r.	≥ 20 Notes: ▪At least 4 ACH of fresh air	[20 ; 24]	[20 ; 60]

Thermal Comfort

Thermal discomfort impairs cognitive performance and affects safety, with 86.1% of surgeons reporting excessive warmth (Cwiklińska et al., 2022). Consistently, predicted mean vote (PMV) values range from +0.75 to +1.25 (Bogdan et al., 2011), due to highly insulating, low-permeability surgical clothing (Table 2). These garments reduce sensitivity to air temperature and velocity changes, limiting ventilation-based thermal control.

Additionally, individual factors cause divergent thermal sensations among the surgical team members. Surgeons and scrub nurses in the microenvironment experience high radiative gains from nearby surgical lamps (Mora et al., 2001) alongside high metabolic rates up to 2.4 met due to stressful, physically demanding roles (Zwolińska and Bogdan, 2013), justifying their warmth complaints. Conversely, anaesthesiologists and circulating nurses have lower metabolic rates (~1.4 met) and work farther from the microenvironment, reducing their exposure to lamp radiation, which, in turn, results in the OR environment being reported as cool (Santana et al., 2024).

Table 2. Surgical clothing characteristics (n.r. = not reported).

Components	Usage	Fabric Material	Microbial Penetration-dry	Thermal insulation, I_{cl} [clo]	Ref.
Scrub suit	Reusable	69 % cotton, 30 % polyester, 1 % carbon fibre	≤ 300 CFU	n. r.	Tammelin et al., 2020
	Single-use	Inner layer: 70 % viscose, 30 % polyester Outer layer: Spunbond Meltblown Spunbond Polypropylene	≤ 100 CFU	n. r.	
Gown	Reusable	Front and sleeves: liquid-proof fabric of higher resistance; Remainder of gown: n.r. % polyester, n.r. % carbon fibre	n. r.	parallel - 0.974; series - 1.303	Bogdan et al., 2011
	Reusable	Front and sleeves: PTFE (polytetrafluorothylene); Remainder of gown: n.r. % polyester, n.r. % carbon fibre	n. r.	parallel - 1.032; series - 1.406	

4 DISCUSSION

The literature provides well-established insights on how physical obstructions, human behaviour, and convective flows interact with ventilation. Thermal comfort, strongly influenced by surgical clothing, warrants further study to assess how ventilation supply environmental parameter adjustments can simultaneously affect surgeons' thermal perception and optimise airflow.

5 CONCLUSIONS

This review highlights key factors shaping the safety of the surgical microenvironment and shows how ventilation, room characteristics, and human behaviour interact to guide strategies that optimise air quality, reduce infection risk, and improve patient care.

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