Effect of unidirectional airflow ventilation on surgical site infection in cardiac surgery environmental impact as a factor in the choice for turbulent mixed air flow

Friedericy, H. J.; Friedericy, A. F.; de Weger, A.; van Dorp, E. L.A.; Traversari, R. A.A.L.; van der Eijk, A. C.; Jansen, F. W.

DOI
10.1016/j.jhin.2024.03.008

Publication date
2024

Document Version
Final published version

Published in
Journal of Hospital Infection

Journal of Hospital Infection 148 (2024) 51—57

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

Effect of unidirectional airflow ventilation on surgical site infection in cardiac surgery: environmental impact as a factor in the choice for turbulent mixed air flow

H.J. Friedericy [a,*], A.F. Friedericy [b], A. de Weger [c], E.L.A. van Dorp [a], R.A.A.L. Traversari [d], A.C. van der Eijk [e], F.W. Jansen [f,g]

[a] Department of Anaesthesiology, Leiden University Medical Centre, Leiden, The Netherlands
[b] Department of Health Sciences, Free University of Amsterdam, Amsterdam, The Netherlands
[c] Department of Cardiothoracic Surgery, Leiden University Medical Centre, Leiden, The Netherlands
[d] TNO, Delft, The Netherlands
[e] Operating Room Department and Central Sterile Supply Department, Leiden University Medical Centre, Leiden, The Netherlands
[f] Department of Gynaecology, Leiden University Medical Centre, Leiden, The Netherlands
[g] Faculty of Biomedical Engineering, Delft University of Technology, Delft, The Netherlands

A R T I C L E I N F O

Article history:
Received 17 August 2023
Accepted 14 March 2024
Available online 25 March 2024

Keywords:
Cardiac surgery
Surgical site infection
Unidirectional air flow
Turbulent mixed air flow
Environmental impact
Carbon footprint

S U M M A R Y

Background: Surgical site infection (SSI) in the form of postoperative deep sternal wound infection (DSWI) after cardiac surgery is a rare, but potentially fatal, complication. In addressing this, the focus is on preventive measures, as most risk factors for SSI are not controllable. Therefore, operating rooms are equipped with heating, ventilation and air conditioning (HVAC) systems to prevent airborne contamination of the wound, either through turbulent mixed air flow (TMA) or unidirectional air flow (UDAF).

Aim: To investigate if the risk for SSI after cardiac surgery was decreased after changing from TMA to UDAF.

Methods: This observational retrospective single-centre cohort study collected data from 1288 patients who underwent open heart surgery over 2 years. During the two study periods, institutional SSI preventive measures remained the same, with the exception of the type of HVAC system that was used.

Findings: Using multi-variable logistic regression analysis that considered confounding factors (diabetes, obesity, duration of surgery, and re-operation), the hypothesis that TMA is an independent risk factor for SSI was rejected (odds ratio 0.9, 95% confidence interval 0.4—1.8; $P>0.05$). It was not possible to demonstrate the preventive effect of UDAF on the incidence of SSI in patients undergoing open heart surgery when compared with TMA.

Conclusion: Based on these results, the use of UDAF in open heart surgery should be weighed against its low cost-effectiveness and negative environmental impact due to high electricity consumption. Reducing energy overuse by utilizing TMA for cardiac surgery can diminish the carbon footprint of operating rooms, and their contribution to climate-related health hazards.

* Corresponding author. Address: Department of Anaesthesiology, Leiden University Medical Centre, Albinusdreef 2, 2333 ZA Leiden, The Netherlands. Tel.: +31 71 526 6046.

E-mail address: h.j.friedericy@lumc.nl (H.J. Friedericy).

https://doi.org/10.1016/j.jhin.2024.03.008

Introduction

Surgical site infections (SSI) are infections that occur within 30 days of a surgical operation, affecting either superficial or deep tissues at the site of operation [1]. In cardiac surgery, postoperative deep sternal wound infection (DSWI) is a rare, but potentially fatal, SSI [2]. The incidence of DSWI (mediastinitis) in cardiac surgery ranges from 0.6% to 8.7% [3–5]; however, DSWI is associated with significant morbidity, mortality and financial costs. Patient-related risk factors for DSWI are multiple and include age, obesity, diabetes and chronic obstructive pulmonary disease [6]. Perioperative risk factors for DSWI include bilateral (particularly non-skeletonized) internal mammary artery use, re-exploration for bleeding, and duration of surgery [3,4]. Most of these risk factors are not controllable, meaning that preventative measures are needed to avoid SSI. SSI guidelines and recommendations consist of preventive measures such as glucose control, timely antibiotic prophylaxis, hair removal with clippers, alcohol-containing skin preparation, nasal *Staphylococcus aureus* decolonization, perioperative normothermia, and incisional negative pressure wound therapy [7–9].

In addition to these preventive measures, operating rooms (ORs) are equipped with heating, ventilation and air conditioning (HVAC) systems. These air treatment systems are intended to prevent airborne contamination of the wound. Frequent and high-quality air filtering with a high-efficiency particulate air filter must ensure that the concentration of airborne pathogens from the skin and nasopharynx of those present in the OR is as low as possible. The traditional way to do this is with a displacement system known as 'turbulent mixed air flow' (TMA).With this type of system, filtered air is blown into the OR, which causes dilution of the airborne bacterial load in the entire room. In the 1970s, ultraclean air (UCA) OR ventilation systems were developed to reduce the microbe-carrying particles to a minimum ($\leq 10/m^3$ at the surgical wound) [10]. Over the years, this type of air treatment system has evolved into what is known today as an 'unidirectional air flow' (UDAF) air treatment system. With this system, air flow can be directed in such a way that the surgical field and the instrument table receive filtered clean air at a high rate directly from an inlet in the ceiling of the OR (Figure S1, see online supplementary material). Within these classifications, many different designs exist for both TMA and UDAF ventilation systems. For instance, there are TMA systems with higher air flows, and laminar air flow systems with lower air flows [11]. The ISO 14644-1 classification is the international standard to describe the performance of different ventilation systems with regard to air cleanliness. Measured using the number of colony-forming units (CFUs), UDAF systems show better performance with regard to the bacteria concentration present in the OR [11,12]. However, there is controversy in the literature regarding whether UDAF actually reduces the incidence of SSI [13]. This lack of scientific evidence led the World Health Organization to issue a conditional recommendation in 2018 against the use of UDAF to reduce the risk of SSI for patients undergoing total joint arthroplasty (TJA) surgery [14]. In a review of original studies, including studies executed before 1990, Whyte *et al*. reported a favourable effect of UDAF on SSI in TJA surgery [10]. Most of the studies that have been carried out on the effect of UDAF in preventing SSI were aimed at TJA surgery, because the insertion of orthopaedic implants leads to increased risk of SSI [15]. Three studies carried out in non-orthopaedic surgery showed conflicting results [16–18].

In cardiac surgery, it is the risk of mediastinitis which results in high costs and a high mortality rate that leads hospitals to implement UDAF systems for open heart surgery. However, to date, to the authors' knowledge, no studies have been conducted on the efficacy of UDAF compared with TMA in preventing SSI in cardiac surgery.

The aim of the present study, undertaken at a single centre, is to assess whether, under the same perioperative institutional SSI prevention measures, there is a difference in the occurrence of SSI in open heart surgery when performed under UDAF compared with TMA conditions. It was hypothesized that TMA is an independent risk factor for SSI in open heart surgery, and that UDAF has a preventive effect with, consequently, a lower incidence of (deep) sternal wound infections.

Methods

Study design

This observational retrospective single-centre cohort study collected data from patients who underwent open heart surgery at Leiden University Medical Centre (LUMC) in the Netherlands in 2019 and 2021. The year 2020 was deliberately not included due to the potential effects of the coronavirus disease 2019 (COVID-19) pandemic on patient selection that year. For the group of patients who underwent surgery in 2019, procedures were performed in ORs with a TMA air treatment system (ISO 14644-1 class 7). On 11th January 2021, the new ORs with UDAF systems (ISO 14644-1 class 5) were put into service for the cardiothoracic surgery department. The Medical Ethical Testing Commission of LUMC gave approval for this study.

All patients who underwent open heart surgery at LUMC from 1st January to December 31st December 2019, and from 11th January 2021 to 11th January 2022, and were aged $\geq$18 years in the study period were included in this study. Patients aged $<$18 years or who underwent procedures other than open heart surgery were excluded.

Data were extracted from electronic patient files using a computer query. Patient characteristics [age, gender, body mass index (BMI) and diabetes mellitus], admission-related variables (urgency of operation, type of operation, duration of operation, re-operation, and duration of admission) and SSI variables (location, depth, wound culture, and treatment) were collected. All missing data were supplemented following manual searches of patient records.

Screening for wound infections was undertaken by searching the medical record course with a computer query consisting of the key words 'wound infection', 'pus', 'VAC' and 'wound outpatient clinic'. These key words were based on known patients with SSI in the study period from the private database of one of the authors (AdW). SSI were categorized on the basis of location (sternal incision, site of venectomy) and depth according to the criteria of the Centers for Disease Control and Prevention (CDC): superficial, deep or organ/space [19]. There was a 90-day follow-up period after the date of surgery, as recommended for cardiac surgery by CDC [19]. Individual records of patients with potential SSI were reviewed manually, and the diagnosis and classification of SSI was established by an experienced cardiac surgeon (AdW).

During the two study periods, all institutional SSI preventive measures (Table S1, see online supplementary material) were the same; there were no changes in the applied bundle of preventive measures, with the exception of *S. aureus* screening, which was not performed in 2021 due to COVID-19 measures.

The characteristics of the two types of ventilation systems that were used in 2019 and 2021 (TMA and UDAF, respectively) are specified in Table S2 (see online supplementary material). In the new ORs with UDAF, the size of the UDAF ceiling air inlet is 3 x 3 m, ensuring that all surgical tables can be placed within the UDAF field. In these ORs, the surgical lamps are integrated in the ceiling, so no obstacles are present between the ceiling and the surgical field, and a 'skirt' is placed around the plenum to stimulate more downflow and to prevent early entry of particles into the protected area [20].

Statistical analysis

All statistical analyses were performed using SPSS Version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics (frequencies and means with standard deviation) were presented for the population characteristics and the surgical procedures, comparing both groups. Population characteristics of the population included age, gender, diabetes, BMI, Euroscore-II, and number of days of admission. Characteristics of the surgical procedures included urgency of operation, type of operation, duration of operation (in min), and re-operation.

The SSI rate was presented as the percentage of the total patients per group, and Pearson's Chi-squared test was used for comparison. Using univariate logistic regression, the frequencies and odds ratios with the corresponding 95% confidence intervals (CI) and *P*-values for potential risk factors for SSI [TMA air treatment, diabetes, obesity (BMI $>$30 kg/m^2), duration of operation $>$320 min, and re-operation] are presented in Table II. Duration of operation greater than the 75th percentile ($>$320 min) was considered as a risk factor for SSI [21]. The associations of SSI risk factors were compared using multivariate logistic regression analysis, which corrected for the TMA air handling system, diabetes, obesity, duration of surgery $>$320 min, and re-operation. The results are presented in Table II, showing the odds ratios, 95% CI and *P*-values.

Results

In total, 1288 patients underwent open heart surgery in the 2-year study period. Of those, 599 patients underwent surgery in 2019 using the TMA air treatment system, and 689 patients underwent surgery in 2021 under UDAF conditions. The characteristics of the included patients and the characteristics of the surgical procedures they underwent are presented in Table I. Patient characteristics (age, sex, diabetes, BMI, Euroscore-II, and duration of admission) were evenly distributed in both groups. In 2021, there were almost 11% more isolated coronary surgeries and almost 7% fewer isolated valve surgeries. This may be explained by the postponement of elective surgeries in 2020 due to the COVID-19 pandemic.

Overall, 29 patients developed an SSI of the sternal wound. The overall incidence of SSI in the TMA group (2.0%) did not differ significantly from the incidence in the UDAF group (2.5%, *P*=0.58). The frequencies of the depth of infection according to CDC criteria in both groups are presented in Figure 1. In the TMA and UDAF groups, 1.0% and 1.3%, respectively, of patients who underwent open heart surgery were diagnosed with mediastinitis (CDC grade 'organ space'). An SSI of the sternotomy wound was diagnosed in 0.8% of patients in the TMA group and 0.6% of patients in the UDAF group. In-hospital mortality in the group of patients with SSI of the sternum was 17% (five cases).

Microbial aetiology could be identified in wound cultures of 55% of patients with sternal SSI; no cultures had been obtained for the other 45% of patients with sternal SSI. *S. aureus* was the

Table I
Characteristics of the study population (*N*=1288)

Characteristic	Type of operating room ventilation	
	Turbulent mixed air flow (2019) (*N*=599)	Unidirectional air flow (2021) (*N*=689)
Age, mean (SD), years	63.6 (11.8)	63.8 (12.2)
Sex		
Male	68.8%	74.3%
Female	31.2%	25.7%
Diabetes	21.4%	21.5%
BMI, mean (SD), kg/m^2	26.6 (4.4)	27.2 (4.3)
Euroscore-II, mean (SD), %	3.75 (5.4)	3.24 (5.8)
Duation of admission, mean (SD), days	12.7 (12.9)	10.5 (10.9)
Urgency of operation		
Elective/urgent	93.7%	93.6%
Emergency	5.5%	5.5%
Salvage	0.8%	0.9%
Surgical procedure		
Isolated coronary surgery	39.7%	50.5%
Isolated valve surgery	36.6%	30.0%
Combined surgery	12.2%	11.6%
Aorta surgery	6.2%	4.6%
Other	5.3%	2.9%
Operation duration		
Mean (SD), min	278 (94)	281 (100)
$>$75th percentile (320 min)	23.0%	26.3%
Re-operation rate	9.0%	8.9%

BMI, body mass index; SD, standard deviation.

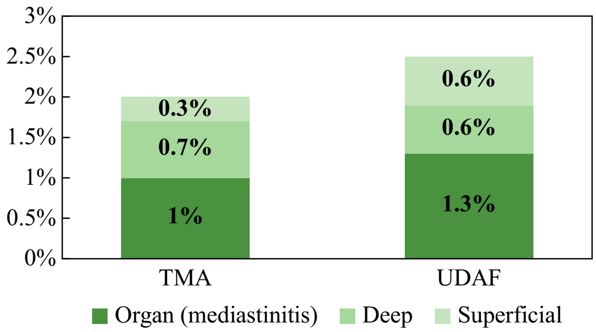

Figure 1. Frequency of surgical site infections distributed by depth, Centers for Disease Control classification. TMA, turbulent mixed air flow; UDAF, unidirectional air flow.

pathogen isolated most often (seven cases), followed by *Staphylococcus epidermidis* (three cases), *Enterococcus faecalis* (two cases) and *Pseudomonas aeruginosa* (two cases), *Klebsiella pneumonia* (one case) and *Serratia marcescens* (one case).

Univariate and multi-variate analysis results are summarized in Table II. In the univariate analysis, SSI of the sternal wound was found to be significantly associated with obesity, duration of surgery >320 min, and re-operation. Air treatment with TMA was not found to be a significant risk factor for sternal wound SSI. Multi-variate analysis found that BMI >30 kg/m^2 and re-operation were the only factors to be significantly associated with sternal wound SSI; diabetes, duration of surgery >320 min, and air treatment with TMA were not significantly associated with sternal wound SSI (odds ratio 0.9, 95% CI 0.4—1.8).

Discussion

The hypothesis for this research was that TMA is an independent risk factor for SSI in open heart surgery. This could not be confirmed on either univariate analysis (odds ratio 0.8, 95% CI 0.4—1.7) or multi-variate analysis (odds ratio 0.9, 95% CI 0.4—1.8). Therefore, under the same institutional SSI preventive measures and with a state-of-the-art (ISO 14644-1 class 5) UDAF system, it was not possible to demonstrate a protective effect of UDAF on the incidence of SSI in open heart surgery. There was no difference in the incidence of SSI between the TMA group (2.0%) and the UDAF group (2.5%, P=0.58). Mediastinitis (CDC grade 'organ space') occurred in 1.0% (TMA) and 1.3% (UDAF) of patients who underwent open heart surgery, with overall in-hospital mortality due to mediastinitis of 17%.

The incidence of mediastinitis and its mortality rate in this study are consistent with the numbers reported in the literature [5]. Due to the risk of mediastinitis in open heart surgery, preferred practice is for this surgery to be performed under UCA conditions. There seems to be no dispute that UDAF results in a reduced bacterial and particle load, which would suggest it to be an important preventive measure for SSI [22]. However, it remains unclear whether this UCA leads to fewer SSI. In light of this scientific uncertainty, it seems justified to consider the effectiveness of UDAF systems in reducing SSI in specific types of surgery, such as cardiac surgery, particularly given the environmental impact and high acquisition and operating costs of UDAF systems [15]. UCA conditions are often, but not always, realized by utilizing UDAF ventilation systems [23]. In research on performance of OR ventilation systems, Romano *et al.* found that the contamination performance in operational conditions of UDAF ISO class 5 systems, such as that used in the present study, had average values of 5.5 CFU/m^3, and were always better than those of TMA systems (72.8 CFU/m^3) [24]. Therefore, in the present study, it can be assumed that the air cleanliness was significantly better under UDAF conditions.

It seems plausible that if there are fewer airborne bacteria due to cleaner air during surgery, there should be less risk of wound infections. However, studies performed over the years on TJA do not give unequivocal results. This may be due, in part, to the methodology of these studies [10,25]. Numerous factors are involved in the occurrence of SSI, and each of these factors can be a potential confounder in studies comparing different types of air handling systems. It is well established that the incidence of SSI depends on patient-related factors, surgery-related factors and preventive measures [9]. For the latter, air cleanliness depends on many factors, such as the type of air handling system, door openings, the position of surgical lamps, plenum size, and type of clothing [15,23]. This multi-factorial aspect of SSI risk and the lack of control over these variables may explain the conflicting results in the literature, as no randomized controlled trials (RCTs) have been conducted recently. In the 1970s, RCTs were conducted as part of the Medical Research Council study [10]. These studies remain very valuable, but much has changed in 50 years in terms of technology and SSI prevention. This means that it is unlikely that all results will be applicable to the current state of affairs, and justifies the authors' suggestion for the need to perform new RCTs.

In a recent single-centre retrospective cohort study with the only variable being the OR ventilation system, Wang *et al.* demonstrated no reduction in the risk of periprosthetic joint infection in TJA due to UDAF [26]. These results are in accordance with the present findings in open heart surgery.

Table II
Association between risk factors and sternal wound surgical site infection (SSI)

Parameter	Univariate analysis				Multi-variate analysis	
	SSI (N=29)	No SSI (N=1259)	OR (95% CI)	P-value	OR (95% CI)	P-value
Diabetes	9 (3.3%)	267	1.6 (0.8—3.7)	0.20	1.6 (0.7—3.6)	0.29
Obesity (BMI >30 kg/m^2)	12 (4.4%)	263	2.7 (1.3—5.7)	0.01	2.4 (1.1—5.2)	0.03
Duration of surgery (>320 min)	13 (4.1%)	306	2.5 (1.2—5.3)	0.01	2.0 (0.9—4.4)	0.08
Re-operation	10 (8.7%)	105	5.8 (2.6—12.8)	0.00	4.9 (2.1—11.1)	0.00
Air treatment with TMA	12 (2.0%)	587	0.8 (0.4—1.7)	0.58	0.9 (0.4—1.8)	0.68

BMI, body mass index; TMA, turbulent mixed air flow; OR, odds ratio; CI, confidence interval.

ORs are a very resource-intensive segment of hospitals, and consequently have a considerable environmental burden. MacNeill *et al*. measured an average carbon emission per OR of 188 tons of CO_2-eq annually [27]. This is approximately equivalent to annual emissions of 95 petrol cars per OR. The carbon footprint of ORs is mainly determined by the direct emissions of greenhouse gases (e.g. inhalation anaesthetics), indirect emissions from HVAC energy consumption, and indirect emissions due to the surgical supply chain and waste disposal [27]. HVAC systems are responsible for 90–99% of energy consumption in ORs [27]. This energy consumption depends, amongst other things, on the type of air treatment system used [11,12]. Alsved *et al*. evaluated the air cleanliness and energy consumption of UDAF and TMA ventilation systems during orthopaedic operations. The energy consumption of the TMA system was 65% less than that of the UDAF system. This was due to high airflow rates of 12,000 m^3/h that are a characteristic of UDAF. However, the air cleanliness in the OR using UDAF was significantly better than that of TMA [11]. In a Norwegian hospital, using mock surgery simulations, UDAF and TMA were compared looking at energy consumption and factors such as outdoor temperature, amount of fresh air supply, heat recovery, and setback strategy when the OR is empty. After outdoor temperature correction, the median electricity consumption of TMA was 45% less than that of UDAF [12]. Both of these studies show that the energy requirements of UDAF are significantly higher than those of TMA. Greenhouse gas emissions due to electricity consumption depend on the percentage of renewable energy used. In 2019, the share of renewable energy worldwide was estimated to be approximately 27%. Therefore, overall, a significant proportion of the energy used globally for OR HVACs results in emissions of CO_2. Furthermore, it will also be important in the future to reduce energy wastage, as there is an imbalance between the amount of renewable energy that can be generated and the ever-increasing worldwide demand for electricity.

These data should be taken into consideration if UDAF cannot be shown to have a positive effect on the incidence of SSI. The climate footprint of health care is equivalent to 4.4% of global net CO_2 emissions, and contributes to climate-related health hazards [28]. The global disease burden from the greenhouse gas emissions of the US healthcare sector alone is estimated to be 209,000 disability adjusted life-years, indicating that health care in itself is detrimental to human health [29]. 'If it does not help, it will not hurt' is therefore not a good strategy when UDAF is chosen as an infection prevention measure in cardiac surgery if, as has been demonstrated in this study, there is no protective effect on the incidence of SSI. Deploying scientifically non-evidence-based infection prevention measures such as these can be classified as overuse, which is responsible, in part, for the carbon footprint of health care. Reducing overuse of health care in general is expected to yield the most significant results in terms of carbon reduction in health care [30]. As HVAC systems have a large impact on the carbon footprint of the OR, it seems effective, based on the present results, to use TMA for open heart surgery, and thus reduce carbon emissions due to overuse of electricity. To prevent DSWI, the focus should be on infection prevention measures that have been proven effective by RCTs [2].

This study has some limitations. The observational nature of the study means that a clinically relevant effect of UDAF cannot be ruled out completely based on the results; a well-designed RCT could possibly do so. The study was retrospective in its design, so the collecting and recording of the data was controlled; this may reduce its reliability in comparison with an RCT. However, as the data were extracted from electronic patient files using a computer query, and all missing data were supplemented after manual searches of patient records, the authors are confident in the reliability of the data. There was a small difference between the cohorts in the number of CABG operations (Table I). A slightly higher incidence of SSI in CABG operations compared with valve surgery has been reported in the literature [4,31]. Statistical analysis of the present data on the type of surgery and SSI risk by means of univariate logistic regression showed no association between CABG surgery and SSI risk (odds ratio 1.046, 95% CI 0.5–2.162). As such, the authors are confident that the difference between the cohorts in the number of CABG operations had no significant influence on the results. The performance of the ventilation systems was not characterized with respect to air cleanliness during the operations, expressed as CFU per cubic metre of air. However, in a recent study on OR ventilation system performance, the UDAF system (ISO 5 class) was shown to be an effective and stable solution to low airborne bioburden contamination [24]. The institutional SSI preventive measures (Table A1, see online supplementary material) were strictly protocolized, and patient characteristics were distributed evenly in both groups (Table I). Although the two cohorts differed only in the type of air treatment used during the procedure, the retrospective study design meant that there was incomplete control for other relevant factors, such as staff work practice, door openings and clothing systems. However, in the two study periods, there was no significant change in staff working practice in terms of number of people present during surgery or staff movements, door openings were always unrestricted, and the clothing system was unchanged. In the context of SSI prevention in the TMA group (2019), a preoperative nares screen on *S. aureus* was executed, and, if positive, a 5-day mupirocin eradication protocol was followed. This was not done in the 2021 UDAF group due to COVID-19 measures. In a recent systematic review of eight studies on targeted mupirocin-based decolonization in patients undergoing cardiothoracic surgery, Wang *et al*. concluded that the results were inconclusive due to contrasting evidence from RCTs and retrospective studies [32]. In view of this conclusion, the present authors are confident that the difference in treatment between the two cohorts had no relevant impact on the results. Another limitation is that this study had a relatively small study population with a very low incidence of the outcome measure; it would benefit the reliability of the study to have a larger study population in order to reduce the chance of statistical error.

Future research should ideally consist of RCTs to demonstrate the effect of UDAF on SSI in multiple types of surgery. Given the low incidence of SSI, an RCT will presumably need to be a multi-centre study to include large numbers of patients. It would need a precise description of the air handling system under investigation, air quality should be measured during operations, and possible confounders should be controlled beforehand. The latter, given the multi-factorial aspect of SSI, may make the implementation of such RCTs unfeasible in practice. However, given the devastating consequences for each patient with DSWI, such research is encouraged. Furthermore, it would be useful to establish a rating of infection prevention methods based on their cost-effectiveness and environmental impact. More environmentally friendly options can be available, implementation of which could be enabled by considering the environmental impact as an additional dimension of quality of care, next to patient safety and clinical effectiveness [33].

In conclusion, based on these results, there seems to be no indication for UDAF to prevent sternal wound infections and mediastinitis in cardiac surgery. With the same effectiveness in preventing SSI as TMA, the use of UDAF should be weighed against its environmental impact due to significantly higher energy consumption. In the current climate crisis, the environmental impact of infection prevention measures such as the air treatment system of an OR should be considered and seen as a dimension of quality of care [33]. HVAC systems have a lifespan of up to 30 years, and when a UDAF system is already implemented, it pays to use renewable energy and reduce its energy consumption. Demonstrated ways to save substantial amounts of energy on HVAC systems include optimization during off-use periods, heat recovery from expelled air, reducing the amount of fresh air added, and reducing the number of air changes [12,22,34,35]. Doing so can improve the carbon footprint of UDAF systems without compromising the air cleanliness in the OR.

Acknowledgements

The authors wish to thank Wybo Hoekstra and Auke de Witte of the Department of Cardiac Diseases Information and Automation of LUMC for their excellent work on the search strategy and data extraction from the LUMC patient database.

Conflict of interest statement

None declared.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Author contributions

HJF: conceptualization, methodology, validation, formal analysis, investigation, writing – original draft, visualization, project administration. AFF: formal analysis, investigation. AdW: investigation, methodology, writing – review and editing. EALvD: methodology, formal analysis, writing – review and editing. RAALT: methodology, writing – review and editing. ACvdE: methodology, writing – review and editing, supervision. FWJ: conceptualization, methodology, writing – review and editing, supervision

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2024.03.008.

References

[1] Owens CD, Stoessel K. Surgical site infections: epidemiology, microbiology and prevention. J Hosp Infect 2008;70:3–10.

[2] Vos RJ, Van Putte BP, Kloppenburg GTL. Prevention of deep sternal wound infection in cardiac surgery: a literature review. J Hosp Infect 2018;100:411–20.

[3] Rehman SM, Elzain O, Mitchell J, Shine B, Bowler IC, Sayeed R, et al. Risk factors for mediastinitis following cardiac surgery: the importance of managing obesity. J Hosp Infect 2014;88:96–102.

[4] Figuerola-Tejerina A, Rodríguez-Caravaca G, Bustamante-Munguira J, María San Román-Montero J, Durán-Poveda M. Epidemiological surveillance of surgical site infection and its risk factors in cardiac surgery: a prospective cohort study. Rev Esp Cardiol (Engl Ed) 2016;69:842–8.

[5] Perezgrovas-Olaria R, Audisio K, Cancelli G, Rahouma M, Ibrahim M, Soletti GJ, et al. Deep sternal wound infection and mortality in cardiac surgery: a meta-analysis. Ann Thorac Surg 2023;115:272–80.

[6] Abdelnoor M, Sandven I, Vengen Ø, Risnes I. Mediastinitis in open heart surgery: a systematic review and meta-analysis of risk factors. Scand Cardiovasc J 2019;53:226–34.

[7] Allegranzi B, Bischoff P, de Jonge S, Kubilay NZ, Zayed B, Gomes SM, et al. New WHO recommendations on preoperative measures for surgical site infection prevention: an evidence-based global perspective. Lancet Infect Dis 2016;16:e276–87.

[8] Ban KA, Minei JP, Laronga C, Harbrecht BG, Jensen EH, Fry DE, et al. American College of Surgeons and Surgical Infection Society: surgical site infection guidelines, 2016 update. J Am Coll Surg 2017;224:59–74.

[9] Seidelman JL, Mantyh CR, Anderson DJ. Surgical site infection prevention: a review. JAMA 2023;329:244–52.

[10] Whyte W, Lytsy B. Ultraclean air systems and the claim that laminar airflow systems fail to prevent deep infections after total joint arthroplasty. J Hosp Infect 2019;103:e9–15.

[11] Alsved M, Civilis A, Ekolind P, Tammelin A, Andersson AE, Jakobsson J, et al. Temperature-controlled airflow ventilation in operating rooms compared with laminar airflow and turbulent mixed airflow. J Hosp Infect 2018;98:181–90.

[12] Fan M, Cao G, Pedersen C, Lu S, Stenstad L-I, Skogås JG. Suitability evaluation on laminar airflow and mixing airflow distribution strategies in operating rooms: a case study at St. Olavs Hospital. Build Environ 2021;194:107677.

[13] Popp W, Alefelder C, Bauer S, Daeschlein G, Geistberger P, Gleich S, et al. Air quality in the operating room: surgical site infections, HVAC systems and discipline – position paper of the German Society of Hospital Hygiene (DGKH). Gms Hyg Infect Contr 2019;14.

[14] World Health Organization. Global guidelines for the prevention of surgical site infections. Geneva: WHO; 2018.

[15] Sadrizadeh S, Aganovic A, Bogdan A, Wang C, Afshari A, Hartmann A, et al. A systematic review of operating room ventilation. J Build Eng 2021;40:102693.

[16] Bosanquet DC, Jones CN, Gill N, Jarvis P, Lewis MH. Laminar flow reduces cases of surgical site infections in vascular patients. Ann R Coll Surg 2013;95:15–9.

[17] Jeong SJ, Ann HW, Kim JK, Choi H, Kim CO, Han SH, et al. Incidence and risk factors for surgical site infection after gastric surgery: a multicenter prospective cohort study. Infect Chemother 2013;45:422–30.

[18] Brandt C, Hott U, Sohr D, Daschner F, Gastmeier P, Ruden H. Operating room ventilation with laminar airflow shows no protective effect on the surgical site infection rate in orthopedic and abdominal surgery. Ann Surg 2008;248:695–700.

[19] Centers for Disease Control and Prevention/National Healthcare Safety Network. Surgical site infection event (SSI). Atlanta, GA: CDC/NHSH; 2022. Available at: https://www.cdc.gov/nhsn/pdfs/pscmanual/9pscssicurrent.pdf.

[20] Traversari AA, Bottenheft C, Louman R, van Heumen SP, Böggemann J. The effect of operating lamps on the protected area of a unidirectional down flow (UDF) system. Herd 2017;10:40–50.

[21] Edwards JR, Peterson KD, Mu Y, Banerjee S, Allen-Bridson K, Morrell G, et al. National Healthcare Safety Network (NHSN) report: data summary for 2006 through 2008, issued December 2009. Am J Infect Control 2009;37:783—805.

[22] Marsault LV, Ravn C, Overgaard A, Frich LH, Olsen M, Anstensrud T, et al. Laminar airflow versus turbulent airflow in simulated total hip arthroplasty: measurements of colony-forming units, particles, and energy consumption. J Hosp Infect 2021;115:117—23.

[23] Aganovic A, Cao G, Fecer T, Ljungqvist B, Lytsy B, Radtke A, et al. Ventilation design conditions associated with airborne bacteria levels within the wound area during surgical procedures: a systematic review. J Hosp Infect 2021;113:85—95.

[24] Romano F, Milani S, Ricci R, Joppolo CM. Operating theatre ventilation systems and their performance in contamination control: 'at rest' and 'in operation' particle and microbial measurements made in an Italian large and multi-year inspection campaign. Int J Environ Res Public Health 2020;17:7275.

[25] Lidwell OM, Lowbury EJ, Whyte W, Blowers R, Stanley SJ, Lowe D. Effect of ultraclean air in operating rooms on deep sepsis in the joint after total hip or knee replacement: a randomised study. Br Med J (Clin Res Ed) 1982;285:10—4.

[26] Wang Q, Xu C, Goswami K, Tan TL, Parvizi J. Association of laminar airflow during primary total joint arthroplasty with periprosthetic joint infection. JAMA Network Open 2020;3:e2021194. e.

[27] MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. Lancet Planet Health 2017;1:e381—8.

[28] Health Care Without Harm. Health care's climate footprint. Reston, VA: Health Care Without Harm; 2019. Available at: https://noharm-uscanada.org/ClimateFootprintReport.

[29] Eckelman MJ, Sherman JD. Estimated global disease burden from US health care sector greenhouse gas emissions. Am J Public Health 2018;108(Suppl. 2):S120—2.

[30] Thiel C, Richie C. Carbon emissions from overuse of U.S. health care: medical and ethical problems. Hastings Cent Rep 2022;52:10—6.

[31] Mannien J, Wille JC, Kloek JJ, van Benthem BH. Surveillance and epidemiology of surgical site infections after cardiothoracic surgery in The Netherlands, 2002—2007. J Thorac Cardiovasc Surg 2011;141:899—904.

[32] Wang L, Ji Q, Hu X. Role of targeted and universal mupirocin-based decolonization for preventing surgical-site infections in patients undergoing cardiothoracic surgery: a systematic review and meta-analysis. Exp Ther Med 2021;21:416.

[33] Bolten A, Kringos DS, Spijkerman IJB, Sperna Weiland NH. The carbon footprint of the operating room related to infection prevention measures: a scoping review. J Hosp Infect 2022;128:64—73.

[34] Cacabelos-Reyes A, Lopez-Gonzalez JL, Gonzalez-Gil A, Febrero-Garrido L, Eguia-Oller P, Granada-Alvarez E. Assessing the energy demand reduction in a surgical suite by optimizing the HVAC operation during off-use periods. Appl Sci 2020;10:2233.

[35] Gormley T, Markel TA, Jones H, Greeley D, Ostojic J, Clarke JH, et al. Cost—benefit analysis of different air change rates in an operating room environment. Am J Infect Control 2017;45:1318—23.