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Bioparticle concentration in operating room air: a comparison between two clothing systems of different source strengths

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SUMMARY

Background: The permeability of surgical scrubs affects the bacterial load in the operating room (OR) air. Bacterial load can be measured by counting fluorescent bioparticles per unit of air. This study aimed to compare fluorescent bioparticle sized $\geq$3 μm per 50 dm^3 of OR air (FBP) in air during primary arthroplasty surgeries using two different staff clothing systems.
Methods: The average FBP for 37 consecutive arthroplasty surgeries using reusable scrubs was compared with 37 surgery type—matched arthroplasties using single-use scrubs. An analysis of covariance (ANCOVA) was conducted to analyse the effects of surgery duration on log10-transformed FBP while controlling for the number of staff members present and surgery duration.
Findings: Mean FBP levels were 101 (95% confidence interval [CI]: 96-107) for the reusable scrubs and 18 (95% CI:16-20) for the single-use scrubs. In the ANCOVA, clothing type was strongly associated with log10-transformed FBP, accounting for 86% of the partial variance ($\eta^2 = 0.86$). In contrast, neither the number of staff nor surgery duration had a significant effect on FBP.
Conclusion: Clothing system permeability to bioparticles is one key factor in achieving air with low levels of bioparticles in OR air. Measuring FBP in real time during arthroplasty surgery is a new possibility for studying the effect of distinct OR-related factors on air bacterial load.

Introduction

Most peri-prosthetic joint infections are believed to have been inoculated at the time of surgery [1]. The primary prevention strategies include pre-operative optimization of the

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patient (e.g. managing medical disorders, adjusting medications that affect the immune system, improving skin condition, and smoking cessation), intra-operative methods (e.g. antibiotic prophylaxis and infection control protocols), sterile techniques (proper handling of the surgical instruments and implants and decolonizing the patient and the staff), and maintaining optimal air quality in the operating room (OR) [2–4]. Optimal OR air can be achieved by preventing bioparticles from entering the air and by using highly effective OR ventilation to remove them from the sterile area [5]. OR air bacterial load can be estimated by volumetric air sampling, counting colony-forming units on a growth plate per 1 m^3 of air (cfu). Several factors affect the number of particles released into the OR air, including the number of people in the room [6,7], their activity level [8], and the permeability of the clothing system used [9].

Source strength is defined as the total number of cfu/s dispersed from a person wearing a particular clothing system [9]. The tighter the woven fabric, the lower the particle permeability. The sizes of airborne bacteria-carrying particles from humans are typically 4–20 μm [10]. There is debate on the extent to which OR air contamination affects the risk of implant-related infection in modern ventilated ORs. A recent systematic review concluded that 'air contamination and SSI (surgical site infection) seem to be correlated' [11].

During arthroplasty surgery, the standard has been set to achieve ultra-clean OR air, defined as cfu <10 [12]. The method using a volumetric air sampler in the OR and then growing the aerobic bacteria on culture plates in the laboratory is cumbersome and labour-intensive. A more convenient method for continuous OR air surveillance is real-time measurement of fluorescing bioparticles per unit volume of air. These methods yield different estimates of OR air bacterial load and are not directly comparable. Although no direct mathematical relationship exists between the measures, they appear to be correlated. A low mean number of fluorescent bioparticle sized $\geq$3 μm per 50 dm^3 of OR air, (hereafter referred to as FBP) is associated with low cfu, whereas a high FBP value indicates higher cfu [13].

This study aimed to compare FBP levels during primary arthroplasty surgeries in a turbulent mixed airflow (TMA) OR using two staff clothing systems with different source strengths. The hypothesis was that the system with the lower source strength would be associated with lower FBP.

Methods

Study design

This is a prospective quasi-experimental cohort study comparing two different clothing systems used during arthroplasty surgery, measuring FBP as an estimate of OR air quality. The study was reported according to STROBE (Strengthening the Reporting of Observational Situdies in Epidemiology) guidelines.

Setting

The study was conducted from January to June 2022 in 2 ORs in a newly built surgery department (2020) at Karolinska University Hospital Huddinge, Stockholm. The ORs (57.6 m^2) are equipped with TMA ventilation and HEPA (high-efficiency particulate air filter) filters (2600 L/s air inflow, 48.8 air-changes/hour). Twenty-four supply air devices, each 60x60 cm in size, are located in the ceiling. Four exhaust air devices are located in the corners, 23 cm above floor level, and another 4 devices are positioned 30 cm below the ceiling.

Clothing systems

Two clothing systems were compared: Mertex P-3477 (Hej-Mar AB, Borås, Sweden), reusable scrubs (no more than 100 washing processes), and Barrier® Clean Air Suit (Mölnlycke Health Care AB, Göteborg, Sweden), single-use scrubs. Both clothing systems had cuffs at the lower end of the trousers, at the end of the short-sleeved arms, and at the bottom and neckline of the shirts.

Mertex P-3477 consists of 69% cotton, 30% polyester, and 1% carbon and fulfils material requirements for 'Resistance to microbial penetration – dry' for clean air suits in the standard EN 13795:2011 (penetration $\leq$300 cfu). The Barrier Clean Air Suit consists of 100% polypropylene and fulfils material requirements for 'Microbial penetration – Dry' for clean air suit according to the standard EN 13795–2:2019 (penetration $\leq$100 cfu).

The entire surgical team wore surgical hoods tucked into the neckline and single-use surgical masks IIR (European standard, EN 14683). Optionally, some surgeons used a sterile surgical space suit (Flyte® Hood and Helmet, Stryker). Scrub nurses and orthopaedic surgeons wore sterile single-use non-woven gowns (Mölnlycke Barrier®) and sterile double surgical gloves.

Prevention measures

The ORs were cleaned in accordance with SIS/TS 39:2025 standards [9]. Patients were decontaminated with a chlorhexidine soap pre-operatively, using whole-body showers the evening before and the morning of surgery. The surgical site was decontaminated using an alcohol-based solution containing chlorhexidine. Unnecessary movements and door openings were kept to a minimum as a routine in the ORs.

Measuring device

Airborne bioparticles sized $\geq$3 μm were measured in real time in 5-s intervals using a Bio Aerosol Monitoring System (BAMS, Zecon AB, Sweden). The BAMS is an optical instrument that samples 5 dm^3 of air per minute. The air passes through a laser beam, and particles in the sampled air will scatter light differently depending on size and can thereby be counted. Particles containing nicotinamide adenine dinucleotide + hydrogen and riboflavin (indicating biological activity) fluoresce and are counted as fluorescent bioparticles per volume of air. Five-second counts of fluorescent bioparticles sized $\geq$3 μm were continuously registered during the surgical procedure. The sum of these counts was divided by the surgery duration (minutes) and multiplied by 10 to obtain fluorescent bioparticles $\geq$3 μm per 50 dm^3, i.e. the average number fluorescent bioparticles sized $\geq$3 μm over 10 min.

The BAMS was located identically during all surgeries, 3.2 m from the operating area and 2.9 m from the corridor door (Figure 1). The measuring sonde for air inflow was 1.2 m above the floor and bent to point towards the operating table. Alternative registrations were saved. The first included all registered time points. The second excluded periods of

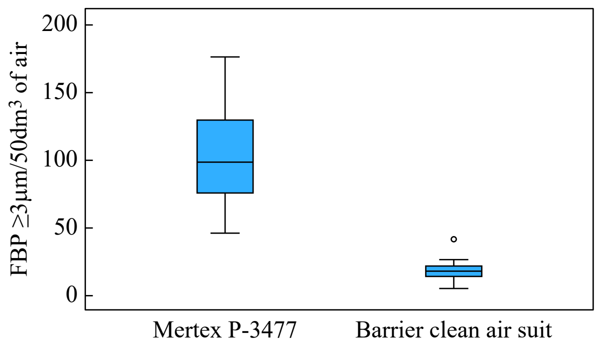

Figure 1. Box plot of fluorescing bioparticles $\geq$3 µm per 50 dm^3 air (FBP), during arthroplasty surgeries using either Mertex P-3477 ($N = 37$) or BARRIER© Clean Air Suit ($N = 37$) clothing systems in turbulent mixed airflow (TMA) ventilation.

distinctly different patterns of registered particles, supposedly due to excessive diathermia emitting vapourized tissue cells into OR air [10].

The BAMS is an integrated part of the Z-Nav quality assurance tool, where OR routines such as the number of sterile staff, the number of unsterile staff, surgery time, and OR routines are logged.

Data collection

First, from the 20th of January to the 24th of April 2022, FBP measures were registered during 39 consecutive elective hip and knee arthroplasties, using reusable scrubs. Two surgeries were excluded due to an interrupted measuring process, leaving 37 for analysis. Then, from the 25th of April to the 15th of June 2022, FBP measures were registered during 37 consecutive surgery type–matched arthroplasties to the first group, using single-use scrubs. Surgery type, surgery time, and the number of staff present in the OR were registered (Table I and appendix 1).

Sample size

Previous FBP sampling at our unit using Mertex P-3477 clothing showed a mean of 100 FBP with a standard deviation of 30. At the start of the study, no published data were available on FBP during surgery using the clothing systems investigated.

Table I
Characteristics of surgical procedures included in the study

	Mertex P-3477		BARRIER© Clean Air	
	N		*N*	
Cemented TKA	14		14	
Cemented THA	12		12	
Uncemented THA	10		10	
Hybrid THA	1		1	
	Mean	**Range**	**Mean**	**Range**
Number of staff	5,4	4–7	5,8	5–9
Surgery duration (min)	107	66–232	102	56–159

TKA, total knee arthroplasty; THA, total hip arthroplasty; min, minutes.

In a previous study by Tammelin *et al.* [14], assessing cfu, a 50% reduction was observed with polypropylene clothing compared with mixed-material garments. Based on an anticipated 25% reduction in FBP when using Barrier Clean Air compared with Mertex P-3477, a sample size of 23 patients per group was required to achieve 80% power and an alpha of 0.05. Considering the uncertainty regarding the assumed means and standard deviations and to ensure inclusion of at least 10 procedures of each surgery type (cemented total knee arthroplasties, uncemented total hip arthroplasties, cemented total hip arthroplasties), the sample size was increased to 37 patients per group.

Statistics

Demographic and procedural data were extracted from the Z-navs database, including surgery codes, the number of staff present, and procedure duration. Descriptive statistics were calculated for demographic variables and for FBP. Due to significant heterogeneity of variances in FBP values, the dependent variable (FBP) was log10-transformed prior to analysis. An analysis of covariance (ANCOVA) was conducted to assess the effect of clothing on log10-transformed FBP while controlling for the number of staff present and procedure duration. All statistical analyses were performed using SPSS version 29 (IBM Corp., Armonk, NY, USA). A detailed list of variables included in the model is provided in Appendix 1, and the corresponding statistical output is presented in Appendix 2.

Results

Demographic data did not differ between the two groups, nor did surgery time (Table I). If measurements were adjusted for diathermy interference, the mean level of FBP using reusable scrubs was 101 (95% confidence interval [CI]: 96-107), and for the single-use scrubs, it was 18 (95% CI: 16-20). Figure 1 presents the distribution of mean FBPs by surgery type.

An ANCOVA was performed with log10-transformed FBP as the dependent variable. The model was statistically significant ($F(3, 70) = 145$, $P < 0.001$), explaining 86% of the variance (adjusted $R^2 = 0.86$). Clothing showed a strong independent association with log10-transformed FBP ($F(1, 70) = 420$, $P < 0.001$; partial $\eta^2 = 0.86$), whereas the number of staff present and surgery duration were not significantly associated with the outcome ($F(1, 70)=1.5$, $P = 0.2$ and $F(1, 70)=0.24$, $P = 0.6$, respectively). Pairwise comparisons showed a statistically significant difference between clothing groups on the log10-transformed FBP scale (mean difference = 0.78, 95% CI: 0.70-0.86, $P<0.001$). When back transformed, this effect corresponds to a 6 times higher FBP level when using Mertex P-3477 relative to Barrier Clean Air Suit (ratio = 6.0, 95% CI: 5.1-7.2).

There were 7 surgeries in the reusable group with diathermia disturbances and 4 in the single-use group. If no adjustments for diathermy interference were made, the mean level of FBP using reusable scrubs was 103 (95% CI: 97–108), and for the single-use scrubs, it was 18 (95% CI: 16–21).

Discussion

We found almost 6 times higher number of FBP using reusable cotton/polyester scrubs than using disposable polypropylene scrubs. The disposable scrubs, Barrier Clean Air Suit, are tighter, are less permeable, and have a lower source strength than the reusable Mertex P-3477 scrubs. Scrubs with lower source strength decrease airborne bacteria, i.e. cfu/m^3 [14,15]. An earlier study conducted in the same OR department as our study showed 3–4 times higher cfu/m^3 when reusable scrubs were used than single-use scrubs [16].

Measured airborne fluorescent bioparticles correlate to aerobic cfu measured during arthroplasty surgery [13,17]. Real-time bioparticle monitoring can thus be used as an indirect measure of bacterial load in the operating theatre air and the risk of wound/implant contamination. Since the bioparticle levels can be shown in real time, as opposed to cfu counting, where the result cannot be obtained until a minimum of 3 days after the surgery, evaluation of the effect of different factors during surgery is more feasible. In our study, the only factor altered between the two test groups was the surgical scrubs used. The difference between groups in bioparticles per minute was consistent and substantial throughout the surgeries analysed. We chose to measure particles sized $\geq$3 μm since measurements of smaller particles are more likely to be disturbed by other particles not being bacteria, i.e. diathermia-vaporized tissue [13,18]. There were periods during 11 surgeries in this study when the pattern of detected particles indicated diathermia interference, also affecting bioparticles $\geq$3 μm. However, these periods did not seem to affect the overall result, as indicated by the almost similar average FBP regardless of whether potential diathermia interference was adjusted for or not. Perhaps these periods are not long enough or too frequent to significantly impact the overall result.

Bioparticle concentration did not seem to be affected by the number of surgical staff members in this study, contrary to previous studies [6,7]. Probably, the difference in FBP for the different clothing systems is so large that the potential FBP difference due to the number of surgical staff was hidden in comparison. Variation in the number of surgical staff between the two groups may also be too small to study that effect. Surgery time did not influence FBP either. Since FBP is the mean number of bioparticles $\geq$3 μm detected during a 10-min period that could be expected, we have no reason to believe that the number of released bioparticles per 10-min period would increase with OR time.

The strength of this study is the use of a novel technique for analysing OR air quality. The technique has previously been correlated to cfu measurements [13], and the results in this study are consistent with previous studies on OR air bacterial load estimated by aerobic cfu/m^3 and use of different clothing systems [16]. Another strength is the conformity between the two groups studied about operative method and surgery types with standardized workflow, minimizing confounding factors.

There are several limitations in this study. First, it was not randomized. We studied two groups consecutively. To compensate for potential differences, we included the same number of specific surgeries in both groups. The time lapse between the groups was caught to a minimum. No difference in the surgical routine, other than the change of type of scrubs, was imposed during the combined study periods. A randomization would have been practically difficult since the study was nested in the normal workflow of the OR department. Second, we have only studied the effect of wearing different surgical scrubs in TMA ventilation. Third, we did not register door openings, the use of sterile surgical space suits, or staff activity levels. However, we do not believe that routines shifted between the two periods.

In conclusion, the result in the present study indicates that the clothing system used is one of the key factors in achieving air with low levels of FBP. Measuring bioparticles in real time during arthroplasty surgery is a new possibility for quality improvement. The method has great potential to study the effects of different workflows in the OR and to give instantaneous feedback to OR staff on factors and activities affecting the bioparticle burden in OR air.

CRediT authorship contribution statement

L. Larsson: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **J. Nordenadler:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **L. Felländer-Tsai:** Writing – review & editing, Visualization, Supervision, Resources, Project administration, Methodology, Conceptualization. **P. Kylmänen:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **H. Björne:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **B. Ljungqvist:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **B. Reinmüller:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **H. Brismar:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Ethics statement

Because of the study design, including no personal data processing and no patient intervention, the Swedish Ethical Review Authority found the study exempt from the Swedish Ethical Review Act and did not find a formal ethical review relevant (Swedish Ethical Review Authority, 2022-03554-01).

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Conflict of interest statement

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2026.01.028.

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