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Potential sources of operating room air contamination: a preliminary study

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SUMMARY

Background: The Neptune® surgical suction system (NSSS) and the Bair Hugger® (BH) forced-air warmer both discharge filtered exhaust or heated air into the operating room (OR), often in close proximity to a surgical site.

Aim: To assess the effectiveness of this filtration, we examined the quantity and identity of microbial colonies emitted from their output ports compared with those obtained from circulating air entering the OR.

Methods: Air samples were collected from each device using industry-standard sampling devices in which a measured volume of air is impacted on to a blood agar plate at a controlled flow rate. Twelve ORs were studied. Sample plates were incubated for one week per study protocol, then interpreted for colony counts and sent for species identification.

Findings: The average colony count from the NSSS exhaust was not significantly different from that obtained from room air samples, however the average count from the BH output was significantly higher (P=0.0086) than room air. Genetic identification profiles revealed the presence of environmental or commensal organisms that differed depending on the source. High variability in colony counts from both devices suggests that certain NSSS and BH devices could be significant sources of OR air contamination.

Conclusions: Our study showed that the BH patient warming device could be a source of airborne microbial contamination in the OR and that individual BH and NSSS units exhibit a higher output of microbial cfu than would be expected compared with incoming room air. We make simple suggestions on ways to mitigate these risks.

Introduction

Great lengths have been taken in previous decades to reduce the risk of surgical site infections (SSIs). Airborne pathogens have been recognized as a source of these infections to the extent that in the USA the Centers for Disease Control and Prevention (CDC) and Healthcare Infection Control Practices Advisory Committee (HICPAC) have made several recommendations related to the handling of operating room (OR) air which include the use of high-efficiency filtration [1]. Our study

Abbreviations: NSSS, Neptune surgical suction system; BH, Bair Hugger; HICPAC, Hospital Infection Control Practice Advisory Committee; HEPA, high efficiency particulate air.

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examined whether two common devices used in the OR may inadvertently be contributing to the burden of airborne microbes and thereby potentially increasing the risk of SSI.

The Neptune® surgical suction system (NSSS) (Stryker Worldwide, Kalamazoo, MI, USA) is a self-contained portable suction system employed widely in hospitals throughout the country, and it has replaced traditional wall suction-based systems in many ORs. It is considered by some to be a less hazardous and more efficient method of handling surgical suction waste [2]. The authors of this study have often observed multi-coloured deposits (possible microbial growth) on the inner walls of the NSSS collection canister that may persist for months despite adherence to the recommended cleaning protocols. Because fluid suctioned from a surgical site is often contaminated with antibiotics administered during surgery, these canisters have the potential to be reservoirs of antibiotic-resistant organisms which, if not properly isolated from the rest of the OR, could have important consequences for SSIs. This isolation depends entirely on the function of the confinement systems within the machine including a high-efficiency particulate air (HEPA) filter.

The Bair Hugger® (BH) forced-air warmer (3M® Company, Maplewood, MN, USA) has been a mainstay of temperature management in the OR for many years. The heated air this device produces is delivered in very close proximity to the patient and the surgical site, and because of this, it has been the subject of previous investigations as a potential source of SSIs. These studies, while not directly linking the device to infections, have shown that it can disrupt the air flow patterns employed in ORs to prevent SSIs [3—7]. The importance of this exhausted air being free of potential pathogens is essential, and to that end each BH contains a HEPA filter located at the air intake at the base of the machine.

The filters in use in both the NSSS and BH should, in theory, ensure that the output or exhaust from these devices is at least as clean as the filtered air entering the OR. HEPA filters are manufactured to a minimum efficiency of 99.97% for the removal of particles greater than 0.3 μm, but both time and particulate loading tend to degrade that efficiency [8]. This is why manufacturers often recommend both interval-based and usage-based replacement schedules for every filter (e.g., 12 months or 500 h of use). At some large institutions including ours, the interval-based replacement schedule presents less of a logistical challenge and is used for these devices.

To test the effectiveness of this filtration at eliminating airborne microbes, we sampled the exhaust air from 12 NSSS and 11 BH devices in 12 separate ORs. This was carried out to count and identify any colony forming units (cfu) they emitted, and then these data were compared with samples from the filtered room air entering the randomly selected ORs in which these devices were in use. We assumed that the HEPA-filtered air emitted from the NSSS and the BH devices would contain lower average colony counts compared with that found at the OR fresh air inlet.

Methods

Air samples were collected from a total of 12 randomly selected ORs following the completion of an open surgical procedure approximately 5—15 min after the patient and surgical team had exited but prior to OR cleaning. ORs at our institution undergo at least 12—20 air exchanges per hour in compliance with State guidelines. In each room, samples were taken from the ceiling OR air inlet, the open NSSS exhaust port at the bottom of the machine and from the open end of the BH hose. These were collected using industry-standard microbial air samplers (Emtek P100 EMTEK LLC, Longmont, CO, USA, or SAS-Super 180 air, Thomas Scientific, Swedesboro, NJ, USA) which collected 200 L of air per sample over a 2-min period. Duplicate samples were taken from each BH and NSSS unit. Both the SAS-Super 180 and Emtek P100 are functionally identical impingement air samplers, which draw a measured volume of air through a manifold to impact a standard culture plate. Blood agar plates were used for all sample collections, and all samples were obtained holding the sampler intake 15—30 cm from each source. NSSS samples were taken near the exhaust port of the suction device, approximately 5—7.5 cm from the floor. BH samples were obtained from the end of the corrugated hose 60 cm from the floor. OR air inlet samples were taken near the ceiling vent, approximately 3 m from the floor. The manifold from each sampler was removed between collections, and all exposed parts were cleaned with 70% isopropyl alcohol and allowed to dry before proceeding to the next OR. Sampling personnel wore normal OR attire including scrubs, mask, head covering, shoe coverings and clean gloves for each event. The only personnel in the room were the three required to perform the sampling.

The Neptune® exhaust, Bair Hugger® inlet and the OR air inlet are equipped with HEPA filters that are changed at regular intervals per manufacturer recommendation and hospital policy. In our institution, these filters are changed approximately every six months in the NSSS and OR air inlet system and every 12 months in the BH devices. The maintenance status for each machine was recorded and filter ages were calculated based on most recent and upcoming dates of service (see Table I). All filters were within their institutional or manufacturer-recommended servicing window and were assumed to be performing at established efficiencies (99.97% exclusion of particles >0.3 μm).

All samples were processed by Pacific BIOLAB (Hercules, CA, USA), an independent laboratory specializing in environmental

Table I
Filter ages based on servicing dates for all sampled devices

Filter age at time of sampling (days)		
OR #	Neptune	Bair Hugger
3	59	181
4	59	362
8	59	—
11	59	271
12	59	301
13	59	271
14	59	240
15	59	332
16	59	89
17	59	301
19	59	28
21	59	271

All Neptune devices had previously been serviced on the same date. Bair Hugger service dates were based on a 12-month maintenance schedule. OR, operating room.

Table II
Total colony forming units (cfu) for each sample site

OR #	Incoming Air		Neptune exhaust		Bair Hugger exhaust	
	Count cfu	per m^3	Count cfu	per m^3	Count cfu	per m^3
3	4	20	6	15	8	20
4	0	0	2	5	12	30
8	0	0	17	42.5	—	—
11	3	15	2	5	12	30
12	3	15	8	20	6	15
13	0	0	0	0	12	30
14	2	10	13	32.5	39	97.5
15	2	10	0	0	6	15
16	2	10	0	0	9	22.5
17	0	0	9	22.5	8	20
19	1	5	7	17.5	4	10
21	4	20	1	2.5	9	22.5
Total	21	105	65	162.5	125	312.5
Average	1.75	8.75	5.42	13.54	10.42	26.04

Conversion to cfu/m^3 for incoming operating room (OR) air was based on a single sample of 200 L, and cfu count was multiplied by 5 for a total sample volume of 1000 L (1 m^3). Counts for the Neptune® surgical suction system and Bair Hugger report the sum of two separate 200-L samples for a total volume of 400 L. This count was multiplied by 2.5 for a sample volume of 1000 L. OR 8 did not contain a Bair Hugger and was excluded from analyses related to this device.

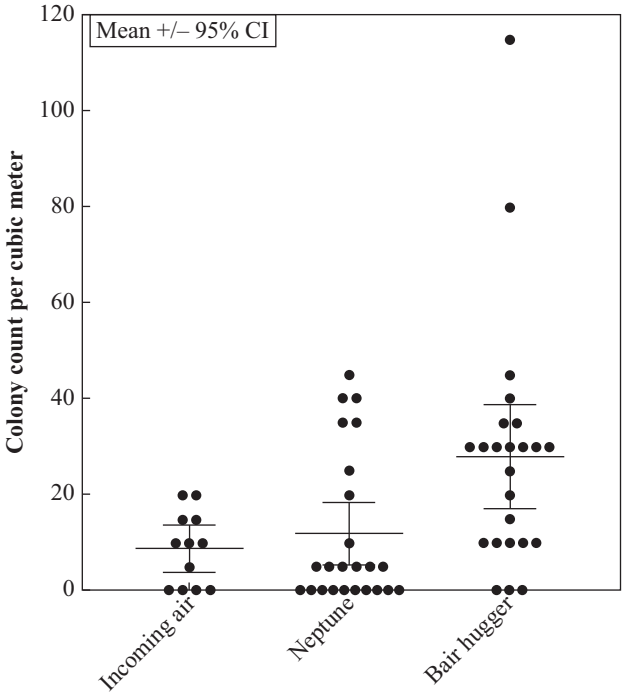

Figure 1. Dot plot analysis of total colony counts (cfu/m^3) in samples from the incoming operating room air, Neptune suction system and Bair Hugger exhausts in individual operating rooms. CI, conflict of interest.

monitoring and compliance with established standards, including ISO and USP environmental testing standards. Sample plates were assigned a number that did not reveal the source of the sample to the microbiology lab staff. Plates were stored in a controlled access incubator cabinet at 30–35 °C for three days followed by four days at 20–25 °C. They were then interpreted once at the end of incubation for colony counts, which were converted to cfu/m^3. Plates were then stored at 2–8 °C for approximately two weeks prior to selection of microorganisms for further investigation. Speciation was performed using Accugenix® strain-typing (Charles River Laboratories, processing lab in Newark, DE, USA), and meticillin susceptibility testing was completed for all *Staphylococcus* spp. Colonies were selected for speciation based on morphology, attempting to identify as many different colony types as possible.

Results

Sample data are shown in Table II. Using the unpaired two-sample Kolmogorov–Smirnoff test, average colony counts (adjusted to cfu/m^3) from the NSSS exhaust (13.54 cfu/m^3) were not significantly different from those obtained from room air (8.75 cfu/m^3; P=0.69); however, the average number of colonies from the BH hose (26.04 cfu/m^3) was significantly higher compared with room air (P=0.0086). This difference persisted when outlier data from OR 14 was excluded (P=0.022). A dot plot representation of sample data in Figure 1 illustrates the high level of variability in our samples compared with room air. Figure 2 shows isolated cfu counts with respect to their OR and sampled device. OR 8 did not contain a BH, and this OR was not included in calculations related to this device.

Our samples contained a range of environmental or commensal bacteria (Table III). A total of 17 species were identified. Eight of these were isolated from all three sample sites, and these colonies were widely present across our sample sets. No meticillin resistance was found amongst the staphylococci tested.

Discussion

Our results confirm that air samples from the BH outlet hose contain a larger number of bacteria on average than the air coming in through the OR ceiling inlets despite regularly scheduled maintenance and the use of high-efficiency filters. The potential risk of blowing air containing bacteria-laden particles in close proximity to the patient and surgical site should not be underestimated. Although the isolates were of low virulence, we feel it is the mechanism of contamination that is the more notable feature of this study, and even opportunistic pathogens should not be dismissed in the presence of an open surgical wound and immunocompromised or otherwise vulnerable patients.

The heated air from a BH is filtered once at the intake manifold underneath the device, and it circulates through the machine and output hose before reaching the patient. All parts following the filter are exposed to OR air, and even with a well-functioning HEPA filter, it is quite possible that particulates from the OR air can enter the open-ended hose and settle within the corrugated tubing only to be re-introduced back into the heated air when the machine is turned on. This concept is supported by two studies that isolated multiple *Staphylococcus* spp. from the internal air path surfaces of the BH. These same investigators confirmed that BH filters in use as recently as 2013 were operating at efficiencies of 61.3–93.8%, well below

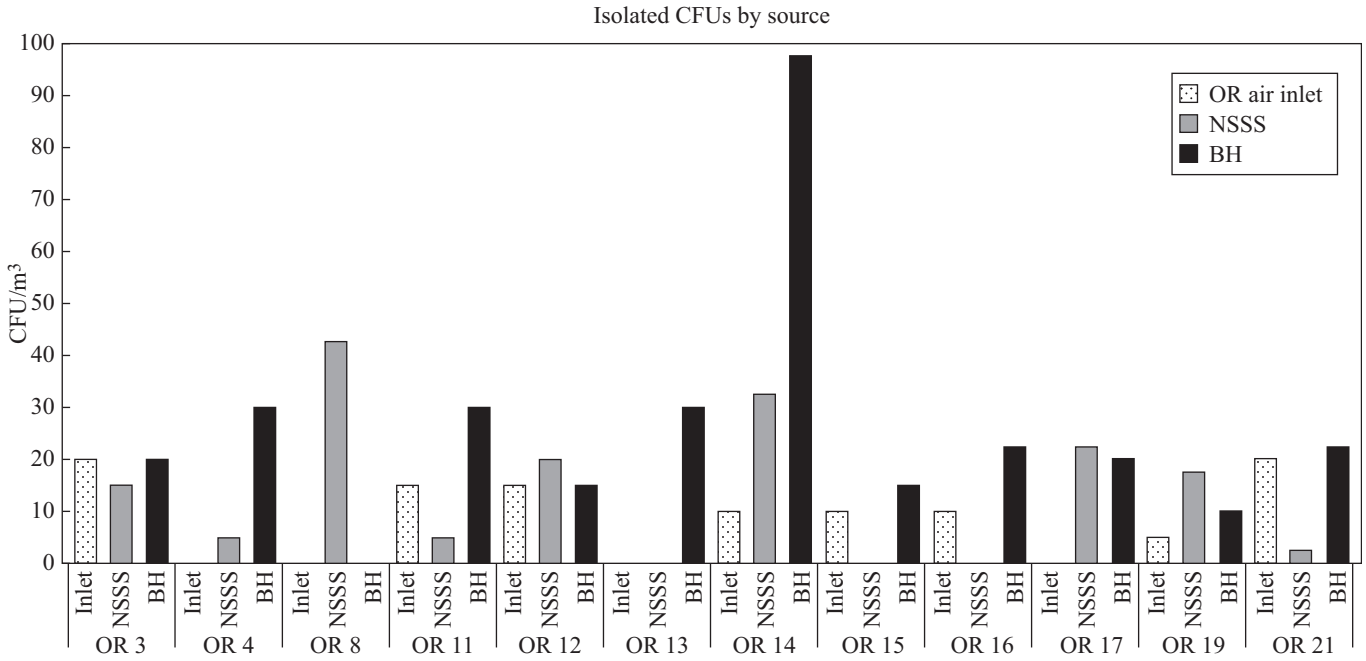

Figure 2. Colony forming units (cfu) by source; cfu grouped with respect to their operating room (OR) and associated Bair Hugger (BH) and Neptune suction system (NSSS) devices.

established standards [9,10]. Cleaning or replacing these hoses is not part of any protocol that we are aware of, and we feel this is an oversight of significant importance. While cleaning and replacing the hose could be technically challenging and cost-prohibitive, placing a second filter at the end of the BH hose may present fewer challenges and would likely alleviate the issue without adversely affecting the device function.

Our study also revealed a concerningly high level of variability from both the BH and NSSS devices compared with OR air inlet samples suggesting that some individual devices may be uniquely hazardous. Functioning at full efficiency, HEPA-filtered air should contain less than 0.03% of particles or organisms entering the filter, which would suggest that for every 3 cfu exiting the filter, 9997 cfu should have been trapped in the device filters, an impressive microbial load. This calculation is overly simplistic, but it illustrates the point that air emitted from these machine filters should at the very least be expected to contain a microbial load that is similar to or smaller than the room air they take in. This was not the case, which may suggest that filter efficiency had been significantly degraded during routine use or that post-filter contamination is a problem. Although we expected no significant difference in

Table III
Organisms cultured by sampling location

OR Air	Neptune exhaust	Bair Hugger
Staphylococcus epidermidis	*Staphylococcus epidermidis*	*Staphylococcus epidermidis*
Bacillus aryabhattai/megaterium	*Bacillus aryabhattai/megaterium*	*Bacillus aryabhattai/megaterium*
Staphylococcus hominis	*Staphylococcus hominis*	*Staphylococcus hominis*
Corynebacterium accolens	*Corynebacterium accolens*	*Corynebacterium accolens*
Staphylococcus saprophyticus	*Staphylococcus saprophyticus*	*Staphylococcus saprophyticus*
Micrococcus luteus	*Micrococcus luteus*	*Micrococcus luteus*
Leifsonia sp.	*Leifsonia sp.*	*Leifsonia sp.*
Rathayibacter rathayi	*Rathayibacter rathayi*	*Rathayibacter rathayi*
	Paracoccus sp.	*Paracoccus sp.*
	Staphylococcus pasteuri	
	Rhodococcus corynebacterioides	
		Corynebacterium sp.
		Deinococcus ficus
		Staphylococcus auricularis
		Micrococcus antarcticus
		Bacillus cereus
		Brevibacillus brevis

No organisms were unique to room air. OR, operating room.

cfu count variability within each of the three sampled sites, we found wide cfu count variability from both the BH and NSSS devices, with some machines contributing markedly more cfu than others. It is important to note here that all BH and NSSS units were within their specified maintenance period, and there was no correlation between BH or NSSS filter age and the number of cfu isolated.

Unfortunately, there is no way to measure accumulated filter load on these devices. It is possible that some BH and NSSS units may inhabit busier ORs and have filters that have outlived their useful filter capacity but remain in service until their service date arrives. A quick estimate for a busy OR (8 operating hours per day, five days per week, 50 weeks per year) yields 2000 operating hours per year. The manufacturer's replacement recommendation on the BH filter is every 12 months or 500 h of use. Even with a large margin of error, this calculation suggests that a 12-month cycle is woefully insufficient for a BH device in use at a busy surgery centre. We believe that the most effective and reasonable solution would be to switch from interval-based to usage-based filter changes. This could be accomplished simply by switching from calendar-based to time-based servicing, because both BH and NSSS devices track usage hours such that staff could ensure filters are changed based on actual usage data. This would be appropriate for both devices, although for the NSSS it may be better to route the machine exhaust through the existing hospital suction system and thereby reduce the need for HEPA filtration.

Looking at the issue more broadly, there is currently no standard for OR air contamination in the USA [11] and the Healthcare Infection Control Practices Advisory Committee actually recommends against regular environmental air sampling except in the setting of an epidemiological investigation. The evidence cited by the committee, however, consists of studies nearly 50 years old [12,13], decades before either of these devices was in use. Their guidelines provide us with evidence-based recommendations such as air pre-filtering, regular HEPA filter changes, positive pressure and laminar air flow systems, and reduction of foot traffic, which appear to be effective at reducing SSIs based on available evidence [1]. However, they do not offer a method of monitoring their effects on the OR environment. We believe that the time has come to re-examine the relationship of airborne cfu with SSI rates and whether routine monitoring could be used as a tool to help reduce the incidence of these infections.

Our study has several limitations. Most notably, this preliminary study was not designed to link these devices to SSIs. This is critical for these results to be actionable on a broader scale, and further studies are needed to establish whether an increased burden of airborne microbes are a relevant source of increased SSIs. Future research should focus on linking organisms isolated from these devices to causative organisms in SSIs or using hospital-level data to identify an association. If the suggested mitigations were implemented, it would be helpful to monitor SSI data closely in the years afterwards to observe any change.

Our sampling methods had both time and equipment constraints. Sampling between surgical cases did not allow sufficient time for remote sampling, which would have been preferable. The NSSS exhaust exits near the floor, and both the BH and NSSS samples were obtained in closer proximity to the floor than the air inlet samples. This potentially exposed them to contamination from turbulent air flow. Fortunately, the exhaust output measured at the sampling distance for the NSSS was 288.7 L/min and 466 L/min from each of its two exhaust ports, and these flows are substantially greater than the sampler flow rate of 100 L/min. The average output flow measured at the sample distance for the BH was 1331 L/min, again substantially greater than the sampler flow rate, thereby minimizing the possibility of contamination by room air. Clinical use of the BH involves attaching the output hose to a large porous blanket in order to distribute the heated air over the patient. These blankets have over 1000 holes and provide no additional filtration, therefore sampling from the blanket itself — while closer to actual OR conditions — would have increased the risk of entraining room air. Additionally, the finding of unique collections of organisms from both the BH and NSSS (see Table III) would suggest that the cfu originated primarily from the sampled devices.

Our sample size was small, and additional research will be needed to confirm our results and apply them to other institutions. Our study did not directly link observed organisms from the BH to the exhaust hose, although others have done so in prior investigations [9,10]. Lastly, although we did not isolate fungi in any samples, we recognize that our sampling methods, in terms of both sampling time and the choice of blood agar growth media, were not optimal for fungal growth. Considering the recent events related to air contamination with fungi at Seattle Children's Hospital [14], it would be important to correct this in future investigations.

In conclusion, the BH is likely a direct contributor to an increased burden of airborne microbes in the OR. Both the BH and the NSSS outputs exhibit wide variability in the cfu emitted into the OR air that could be related to inadequate filter replacement or technical faults in the exhaust design. To carry these ideas forward and drive future research, we are of the opinion that prospective studies should be conducted to establish whether there is a correlation between airborne microbe contamination in the OR and SSI. We also believe that there should be a US standard for OR air contamination. Without standards in place, there is unfortunately little incentive (or funding) to monitor and mitigate potential sources of OR air contamination. In the meantime, we believe it would be prudent to consider usage-based rather than calendar-based filter replacement schedules for HEPA filters, simple design improvements in the BH device to address the settling of particles within the exhaust hose, and potentially routing NSSS exhaust outside the hospital via the existing suction system. We hope that this study will be the impetus for future efforts to minimize/eliminate airborne sources of SSI.

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Conflict of interest statement
The authors have no conflict to declare.

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