The Relationship between Bacterial Load and Initial Run Time of a Surgical Helmet

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Abstract

Background: Periprosthetic joint infection (PJI) is a complication of arthroplasty surgery with significant morbidity and mortality. Surgical helmets are a possible source of infection. Pre-existing dust and microorganisms on its surface may be blown into the surgical field by the helmet ventilation system.

Methods: Twenty surgical helmets at our institution were assessed through microscopy and polymerase chain reaction testing. Helmets were arranged with agar plates under the front and rear outflow vents. Helmets ran while plates were exchanged at different time points. Bacterial growth was assessed via colony counts and correlated with fan operating time. Gram staining and 16S sequencing were performed to identify bacterial species.

Results: The primary microbiological contaminate identified was Burkholderia. There was an inverse relationship between colony formation and fan operating time. The highest number of colonies was found within the first minute of fan operating time. There was a significant decrease in the number of colonies formed from the zero-minute to the three (27 vs 5; \( P < .01 \)), four (27 vs 3; \( P = -.01 \)), and five-minute (27 vs 1; \( P < .01 \)) time points for the front outflow plates. A significant difference was also observed between the one-minute and four-minute time points (\( P = .046 \)).

Conclusion: We observed an inverse relationship between bacterial spread helmet fan operation time, which may correlate with dispersion of pre-existing contaminates. To decrease contamination risk, we recommend that helmets are run for at least 3 min prior to entering the operating room.

Keywords

Arthroplasty, infection, surgical helmet

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Introduction

Periprosthetic joint infection (PJI) is a complication of arthroplasty surgery that is associated with significant morbidity and mortality.¹,² To combat high rates of infection the Charnley whole body exhaust-ventilated suit was developed in the 1960s which utilized negative pressure to decrease contamination of the surgical field.³ Significant decreases in reported infection rates prompted wide adoption however, the associated inflow-outflow tubes proved cumbersome for the operating room.⁴–⁵ Consequently, modern surgical helmet systems (SHS) were developed which provide a stand-alone suit that utilizes a fan to circulate air within a surgical hood cover and gown. These modern suits provide excellent splash protection but their influence on rates of postoperative infection and surgical field contamination is unclear.

Several studies have investigated the association of the SHS and rates of periprosthetic joint infection. Hooper et al. conducted a large retrospective analysis of a joint registry in New Zealand over a 10-year period and found that personal protective ventilation suits were associated with increased rates of infection in total knee and hip arthroplasty.⁶ However, more recent studies have not corroborated
these findings. A follow-up analysis of the same New Zealand registry between 2000 and 2014 found no associated increase rate of infection when using the suits.\(^7\) Namba et al. also found no increased infection risk in surgical ventilation suit use compared to standard surgical clothing from an analysis of a United States joint registry from 2001 to 2009.\(^8\) A systematic review by Young et al. assessed infection and wound contamination rates in both the SHS and the Charnley suit.\(^9\) While the Charnley suit was reported to provide better protection against infection, there was not sufficient evidence to suggest that the SHS increased infection or contamination rates.

Recent studies have been conducted to better characterize the likelihood of surgical field contamination by surgical helmet systems, as well as the potential mechanisms. Vijaysegaran et al. compared particle and microbiologic emission rates from SHS and standard surgical clothing.\(^10\) The authors found higher rates of both particle and microbiologic emission in SHS. Two studies assessed timing of surgical helmet fan activation and concluded that early activation prior to gown dressing increased contamination rates of both the surgeon and scrub nurse.\(^11,12\)

Given the previous research, we conducted a prospective microbiological study examining potential contamination. The primary aim of this study was to determine the possibility of surgical field contamination due to the outflow of the surgical helmet systems and preexisting dust on the helmet. A secondary aim was to determine if there is a relationship between contamination rate and length of fan running time that could result in a recommendation for clinical use to help lessen the possibility of contamination. We hypothesize that surgical helmets are potentially a source of contamination and that there is an inverse relationship between contamination spread and running time of surgical helmet fans.

### Methods

This experiment consisted of two parts. First, we wanted to prove that there were in fact contaminants on the helmets and characterize what these representative bacteria were. This was important because it provided proof of concept for the second, larger part of our study. The second part was to assess whether there was a time component where contamination would decrease as the particles on the helmet outflows would dissipate. Our institution uses the Flyte Personal Protection System (Stryker Instruments, Kalamazoo, MI).

To determine the representative bacteria on the helmets, they were selected from our storage closet and swabs from multiple locations were taken, including the buttons, the outside of the helmet, head cushion pads, battery receptacle, intake and exhaust outlets, and the fan. Additionally, the helmet storage closet and battery charger were sampled. Samples were then swabbed onto agar plates (LB broth with agar; Lennox) and analyzed by Gram staining\(^13\) and 16S polymerase chain reaction (PCR).

As controls, we used an un-swabbed plate as a negative control and an oral swab as a positive control. We identified three different apparent bacterial species based on colony morphology, which we then labeled as bacterial groups 1, 2, and 3. Bacteria were isolated from a region of the original plates that were densely populated with bacterial group 1 and no other contaminants. Bacterial groups 2 and 3 were isolated from colonies from re-streaked plates. Using isolated colonies, 16S PCR was performed with the standard primers 515F (5′ GTGYYACGCMGCCGCGGTAA) and 806R (5′ GGACTACNVGGGTWTCTAAT).\(^14\) Bacterial colonies were lysed in 10 μl water, first by freezing for 10 min at −80 °C, then heating at 95 °C for 10 min. 2 μl of the lysed bacterial was used in a 50 μl in a PCR reaction with Phusion DNA Polymerase (New England Biolabs). The resulting ~300 bp product was sequenced by Sanger sequencing (Eurofins). 16S sequences were screened for matches by BLAST (NCBI).

The second part of our study aimed to assess the relationship of contaminate spread and fan exhaust time based on our hypothesis that the rate of contamination would decrease as the fan continues to run. We created a sterile field in our laboratory to simulate an operating room. Twenty surgical helmets were placed on a table with sterile drapes, no outside airflow and were separated by partitions to prevent cross contamination from adjacent helmets. We set an agar plate in line with the front outflow vent and an additional plate in line with the rear outflow vent. The plates were 8 inches from the vents and the distance was kept constant throughout the experiment. Once the plates were properly positioned, the helmets were turned on with fans running at their baseline setting.

Each helmet was tested in the following fashion. Using sterile gloves, for each helmet plates were switched every minute for six minutes at the front vent and every minute for two minutes at the rear vent. These time points were determined to be appropriate after a trial run. The trial run demonstrated a sharp drop off in colony formation after 3 min in the plates placed by forward facing vents and a sharp drop off after one minute for plates placed by rear vents. For each helmet six plates were collected for the front facing vents and three plates were the rear facing vents for their respective time points. After completion of trials, we placed the plates in the incubator for 24 h and completed a colony count. We recorded each distinct colony for every plate and analyzed the data. Plates with colonies were sent to be analyzed by microbiology to confirm that the bacteria were the same as the bacteria grown from the first helmets that were swabbed. We used microscopy to confirm that the colonies were the same pathogen in regard to morphology and gram stain. Colony counts were averaged for each group. Prior to comparison, Shapiro-Wilk tests were conducted to assess normality and no groups were found to be normally distributed. As such non-parametric Freidman test were performed to compare the groups, followed by Dunn’s multiple comparison tests to identify groups that
differed. Statistical significance was accepted for p-value less than .05 and all analyses were conducted using the Prism (Version 9.4.0, GraphPad) software package. We used every helmet available to us.

There was no outside funding, and the study was IRB exempt.

Results

Baseline Contamination

Initial assessment of surgical helmet contamination demonstrated clear bacterial growth on the plates. No growth was found from our surgical closet and battery charger samples. The colonies formed were small and opaque and the bacteria that grew were Gram negative rods in clusters and Gram positive/variable rods (Figure 1). There was no growth on the negative control plate and the bacterial growth on the positive control (oral swab) was different from that taken from the helmet. The 16S PCR from both phases revealed the primary bacteria on all the test plates to be *Burkholderia*, but of an unknown subspecies. In addition, we identified two different *Bacillus* species, most closely related to *Bacillus cereus* and *Bacillus thuringiensis*.

Bacterial Growth Related to Helmet Fan Running Time

Colony formation occurred in plates placed at both front and rear vents of the surgical helmets (Figure 3). For the initial plates in the sequence, the front outflow plates grew 27 colonies and eleven of the rear outflow plates grew 13 colonies. At the one-minute point, the front outflow plates grew 20 colonies, and the rear outflow grew 11 colonies. The two-minute point produced 20 colonies from the front outflow and 1 from the rear outflow. At the three-, four- and five-minute time points the front outflows collectively grew 5, 3 and 4 colonies respectively. Regarding the average number of colonies formed, there was a clear trend that showed a decrease in average colony number over time from both front and rear outflows (Figure 2). There was a statistically significant decrease in the total number of colonies formed from the zero-minute to the three (27 vs 5; *P* = <.01), four (27 vs 3; *P* = <.01), and five-minute (27 vs 4; *P* = <.01) time points for the front outflow plates (Figure 3). A significant difference was also observed between the one minute and four-minute time points (*P* = .046).

Discussion

Ventilation helmets are widely used in orthopaedic surgery, especially in joint arthroplasty. Infection in total joint arthroplasty represents a devastating complication.1,2 As such, any interventions that could potentially decrease the risk of periprosthetic infections would be valuable. Our results confirmed our hypothesis and demonstrated that surgical helmets are a potential source of contamination. We found that the highest rate of contamination spread occurs within the first few minutes of turning on the surgical helmet fan. There was an inverse relationship where we observed a decrease in colony formation with increasing time. Specifically, we found that after 3 min of airflow the risk of potential contamination significantly decreases.

The samples from the helmets in both phases of the study were heavily contaminated by a bacterium consistent with *Burkholderia*. Some species of *Burkholderia* are pathogenic and while this may be a concerning contaminant, it is not surprising to find *Burkholderia* in hospitals. This bacterium was found on every sample provided except the positive and negative controls. There have been several studies describing septic arthritis secondary to *Burkholderia*, including a case of periprosthetic infection in an immunocompetent patient.15–17 As such, any interventions that could potentially decrease the risk of periprosthetic infections would be valuable. Our results confirmed our hypothesis and demonstrated that surgical helmets are a potential source of contamination. We found that the highest rate of contamination spread occurs within the first few minutes of turning on the surgical helmet fan. There was an inverse relationship where we observed a decrease in colony formation with increasing time. Specifically, we found that after 3 min of airflow the risk of potential contamination significantly decreases.

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![Figure 1](image-url). Bacterial microscopy and gram stain showing gram negative rods, gram positive rods, and gram Variable rods. Scale bar is 10 μm.
sequencing identifying them as *Bacillus* members. Despite both being members of the *Bacillus* genus, the bacteria were clearly different from each other. The colonies formed were different in size and shape. The gram-stains looked different and the 16S sequences have no significant similarity when compared to each other. In one study, *Bacillus* was implicated in one fourth of all wound complications in total hip arthroplasty.

Our study design allowed us to observe the correlation between time that the fan is running and amount of expelled contamitants quantified by colony count. An interesting finding was that there was an objective difference between contaminant “drop-off” time when examining the front and rear outflows. While the front outflow did not drop off until the 3-min mark, the rear outflow dropped off after only 1 min. This may be due to the decreased surface area of the rear outflow pathway compared to the front outflow. It also takes a sharp 90-degree turn where the front flow remains more linear.

These findings can provide guidance on how to safely use helmets in a way that decreases contamination risk in orthopaedic surgery. As mentioned previous studies by Hooper et al. demonstrated that personal protective ventilation suits may increase rates of infection in arthroplasty surgery and attributed it to. There have been two recent studies that looked at timing of helmet fan activation. Kang et al. used ultraviolet light and fluorescent powder to assess airborne contamination. They found that early fan activation resulted in contamination of the body and also the scrub nurse. They recommended activation of the helmet after the surgeon was gowned and the gloves were applied. A major limitation of the study was that they used a powder that was representative of potential dust and directly applied to the helmets. Our study differed in that we analyzed helmets that were unaltered without adding foreign material and isolated pathogens. Hanselman et al. also used fluorescent

![Figure 2. Total number of colonies from front and rear outflows.](image-url)
powder with helmets, but looked at contamination of drapes in addition to body and scrub nurse contamination. They also noticed the largest contamination at initial activation. In their discussion they pointed toward future studies that would isolate bacteria and look at particle counts. Our study addresses both suggestions.

Typically, these helmets are placed, and the battery is inserted right before the surgeon scrubs. This may not provide enough time for any potential dust or contaminants that may be on the helmet to dissipate. Our recommendation from our study would be to allow the helmet to run for at least 3 min prior to entering the operating room to decrease the risk. Although this practice could significantly decrease the risk of potential contaminants from the helmets, it would not eliminate the risk as we still observed infrequent colonies at later time points. We also observed dust on plates at 4 or 5 min that did not grow out any bacteria but may require different media or longer incubation times. To minimize the risk, we would recommend waiting to place the battery until after the sterile hood is donned over the helmet by the scrub tech. This may prevent any bacteria or contaminants from passing through the hood and onto the field.

There are several limitations to the study. One limitation is that we only had 20 helmets available, as such we used them all and did not perform a power analysis. We were still able to demonstrate a statistically significant difference between time point in the total number of colonies formed from the zero-minute to the three (27 vs 5; \( P = .01 \)), four (27 vs 3; \( P = .01 \)), and five-minute (27 vs 4; \( P = .01 \)) time points for the front outflow plates. Another limitation is that there is no set guideline for helmet storage or cleaning in our institution. Helmets are typically wiped down after surgery and placed into the cabinet. There is no specific protocol or system to ensure uniformity. This practice is not isolated to our institution as the authors have observed this same practice at all institutions where they have used the helmets and a protocol is not recommended by the manufacturers.

While the cabinet could be a potential source of bacteria or contamination, our swabs of the cabinet were negative, indicating this was not the source of bacteria and likely is a result of handling the helmet. A set protocol could remove any confounding variables and could be used along with our recommendations to further limit contamination risk. Another limitation is that we only used LB broth agar and an incubation time of 24 h at 37 degrees Celsius. Some bacteria may require different media, longer incubation time or different temperature, such as \( C. \) _acnes_. We also did not perform PCR analysis for every single colony; however, we did use microscopy to confirm that they were the same bacteria morphologically. Future studies could include additional institutions, more helmets, plates obtained from helmets while in use in the operating room in real-time, a set protocol for cleaning and storing the helmets, and different culture media with different incubation times and temperatures. We also plan on exploring the rate of infection with \( B. \) _korderia_ in our institution.

**Figure 3.** Average colonies from front and rear outflow vents. *\( P < .05 \) **\( P < .01 \).
Conclusion
Surgical helmets at our institution are colonized by bacteria that may be a source of contamination. There is an inverse relationship between contamination spread and time that the outflow fans are engaged. We recommend that helmets are run for at least 3 min prior to entering the operating room to decrease the risk of contamination.

Declaration of Conflicting Interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Committee Approval
This study did not involve humans, or human data, or animals and was IRB exempt.

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Study Location
All work was completed at Stony Brook University Hospital.

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