

Forced-air warming discontinued: periprosthetic joint infection rates drop

Scott D. Augustine

Augustine Temperature Management
LLC, Eden Prairie, MN, USA

Abstract

Several studies have shown that the waste heat from forced-air warming (FAW) escapes near the floor and warms the contaminated air resident near the floor. The waste heat then forms into convection currents that rise up and contaminate the sterile field above the surgical table. It has been shown that a single airborne bacterium can cause a periprosthetic joint infection (PJI) following joint replacement surgery. We retrospectively compared PJI rates during a period of FAW to a period of air-free conductive fabric electric warming (CFW) at three hospitals. Surgical and antibiotic protocols were held constant. The pooled multicenter data showed a decreased PJI rate of 78% following the discontinuation of FAW and a switch to air-free CFW (n=2034; P=0.002). The 78% reduction in joint implant infections observed when FAW was discontinued suggests that there is a link between the waste FAW heat and PJIs.

Introduction

It is now generally recognized that in the absence of active warming, most surgical patients will become clinically hypothermic. It has also been shown that mild perioperative hypothermia is detrimental to a variety of outcomes including increased soft tissue infections (SSI),^{1,2} increased bleeding and transfusion requirements,^{3,4} increased risk of morbid cardiac events,⁵ prolonged recovery and prolonged hospital stays.¹ As a result of these studies and others like them, FAW has become a Standard of Care for most surgical procedures.⁶

In 2009, we reported the results of our laboratory research showing that the waste air from FAW is not simply benign waste air, but is also approximately 1000 watts of waste heat (www.Heat-rises.blogspot.com). In some circumstances, the waste heat and air escapes from under the surgical drape near the floor, where it warms the contaminated air normally resident near the floor.

The contaminated warm air forms into convection currents that rise along the sides of the surgical table, mobilizing the floor bacteria into the sterile surgical field above the patient. In other circumstances, the waste heat radiates through the surgical drape, inducing a tornado-like vortex near the anesthesia screen. This tornado-like vortex has been shown to vacuum contaminants from the floor and deposit them into the sterile surgical field.

The fact that waste FAW heat causes contamination of the sterile surgical field has been corroborated by seven peer-reviewed, published studies.⁷⁻¹³ One study by Legg et al., for example, showed that there are 2000 times more contaminating particles above the surgical site when FAW is used than with air-free CFW.⁷

It has been shown that the concentration of contaminants in the air of the sterile surgical field correlates positively with the risk of PJI during total joint replacement surgery.¹⁴⁻²⁰ It is also known that in contrast to soft tissue SSIs, which require an inoculum of more than 1 million bacteria,²¹ a single bacterium can cause a catastrophic PJI, and that the bacterium is usually an airborne contaminant.¹⁶⁻¹⁸ Therefore, it is only logical to suspect that the contamination from the rising waste FAW heat could increase the risk of PJIs.

A large retrospective outcome study by McGovern et al, showed a correlation between the rising waste FAW heat and the majority of deep joint infections in total joint replacement surgery.⁸ The investigators reported a 74% reduction in PJIs when they discontinued the use of FAW. The lower infection rates were achieved using air-free CFW warming: *[FAW] Patient warming ventilation disruption was associated with a significant increase in deep joint infections...*⁸

Similarly, airborne contamination has recently been linked to heart valve infections.²² The FDA and the chain of infection (CDC) have both issued warnings about Nontuberculous *Mycobacterium* (NTM) infections associated with heater-cooler devices (HCD) used during cardiac surgery.^{23,24} Heart valve infections were genetically linked to *Mycobacteria chimaera* growing in the water bath of the HCD machines, which are then aerosolized into the air of the operating room by the cooling fan of the HCD. The contamination and infections from both HCD and FAW share the following traits: biofilm-forming organisms are growing within the inaccessible parts of the devices that cannot be disinfected or cleaned (FAW also mobilizes skin bacteria shed from the surgical staff, which has settled to the floor); the organisms are

Correspondence: Scott D. Augustine, Augustine Temperature Management, 6581 City West Parkway, Eden Prairie, MN, 55344, USA.
Tel: +1.952.465.3502 - Fax: +1.952.465.3501.
E-mail: saugustine@augbiomed.com

Key words: Infection; Wound; Surgical site infection; Nosocomial infections; Health care associated infections.

Contributions: SDA gathered the data and wrote the paper.

Conflict of interest: SDA is the founder, CEO and holds equity in Augustine Temperature Management, LLC, the manufacturer of HotDog® CFW.

Received for publication: 6 December 2016.
Accepted for publication: 15 January 2017.

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Orthopedic Reviews 2017;9:6998
doi:10.4081/or.2017.6998

aerosolized by high-velocity warm air blown into the operating room by the HCD and FAW equipment; the warm air forms into convection currents and rises as all warm air does; the rising convection currents of warm air easily penetrate the protective downward airflow of the ultraclean ventilation system; the airborne bacterium settles on the implanted foreign material (cardiac valve or hip/knee replacement) that is highly susceptible to infection; the bacterium protects itself in a biofilm coating and sprouts into an infection up to a year later.

FAW is a far worse offender than HCD: more waste heat (1000 watts), as much or more blowing air (40-50 cfm), and exhaustion of the waste heat and air inside the ventilation flow field. The McGovern study suggests that up to 74% of the 20,000 hip and knee implant infections that occur annually in the US may be caused by FAW. This is a very significant, but easily solvable, public health problem.

Materials and Methods

This study is designed to investigate periprosthetic joint infection (PJI) rates while using FAW (Bair Hugger®, 3M, St. Paul, MN, USA) compared with air-free CFW (HotDog®, Augustine Temperature

Management, Eden Prairie, MN, USA). The measured outcome in each of these studies is PJI. This multicenter retrospective outcome study consists of data reported by three hospitals.

Each hospital report shares a study design similar to the McGovern study. In each study, a baseline PJI rate was determined for the FAW control group over a one-year period of time (t_{FAW}). FAW was then discontinued, and the hospital switched to air-free CFW warming. Any infections occurring during the first two months after the switch in warming technologies were disregarded. Given that PJIs do not necessarily occur in the immediate postoperative period, it would be impossible to know if an infection occurring during the *washout period* came from the FAW or CFW time period. Starting with month three of the CFW period, the PJI rate was determined for the following 6-24 months of data collection (t_{CFW}). The changes in PJI rates from t_{FAW} to t_{CFW} were then determined.

Only hospitals reporting that no other significant changes were made to their surgical and antibiotic prophylaxis protocols during the study period qualified to be part of this study. No effort was made to standardize surgical protocols, the assumption being that the averaging of the multicenter data would offset minor variations in protocols. No effort was made to control for demographic variables, with the assumption being that the average patient population using a given hospital for total joint replacement surgery does not change appreciably from year to year.

Model selection and parameter significance tests were performed by comparing differences in model deviance to the expectation value under the χ^2 distribution (likelihood ratio test), 0.5 was added to each cell using Haldane correction for sparse observations. A paid, independent statistician performed statistical calculations.

Results

As shown in Table 1, each of the three hospitals reported in this study showed significant decreases in the PJI rates (81, 100 and 34%) when FAW was discontinued in orthopedic surgery. In each case, the lower PJI rate was achieved while using air-free CFW. The three hospitals reported in this study were the first three that the authors contacted. No other hospitals were omitted from the study for any reason.

Center #1 is a medium-sized independent regional healthcare network. Their PJI rate while using FAW was 1.55%, which decreased to 0.29% with CFW, a decrease of 81%. Center #2 is an independent orthopedic and sports institute. Their PJI rate while using FAW was 2.28%, which decreased to 0.0% with CFW, a decrease of 100%. Center #3 is a medium-sized community hospital. Their PJI rate while using FAW was 1.57%, which decreased to 1.03%

Table 1. Periprosthetic joint infection results.

Patient warming device	Developing infection, n (%)	Not developing infection, n (%)	Odds ratio (95% confidence interval)	P
Center #1				
Conductive fabric	2 (0.3)	675 (99.7)	1.0	0.029 ^s
Forced air	6 (1.5)	382 (98.5)	4.59 (1.06, 19.85)	
Center #2				
Conductive fabric	0 (0.0)	218 (100)	1.0	0.031 ^s
Forced air	4 (2.3)	171 (97.7)	11.47 (0.61, 214.43)	
Center #3				
Conductive fabric	2 (1.0)	192 (99.0)	1.0	0.70 ^s
Forced air	6 (1.6)	376 (98.4)	1.33 (0.31, 5.78)	
Multicenter pooled results				
Conductive fabric	4 (0.4)	1085 (99.6)	1.0	0.002 ^s
Forced air	16 (1.7)	929 (98.3)	4.28 (1.50, 12.19)	

Table 2. Chain of infection analysis.

Chain of infection methodology	HCD	FAW
1. Infectious agent	Biofilm producing <i>Mycobacterium chimaera</i>	Biofilm producing skin bacteria, especially <i>Staphylococcus</i>
2. Reservoir	The inaccessible internal water-flow pathway of the HCD	i) The inaccessible internal airflow pathway of the FAW blower; ii) the skin of the surgical staff
3. Portal of exit	Aerosolized into and exhausted with the heated cooling air	i) Aerosolized into and exhausted with the heated air; ii) skin cells and bacteria shed into the air of the OR from the surgical staff
4. Mode of transmission	i) Waste heat rises outside the ventilation flow field and is then entrained into the downward ventilation airflow; ii) The waste heat from the HCD is blown inside the ventilation flow field near floor. Much like the waste heat from FAW, it then rises	The waste FAW hot air escapes from under the lower edge of the surgical drape near the floor inside the ventilation flow field. It warms the contaminated air that is normally resident near the floor. The waste heat and the warmed contaminated floor air then rise alongside the surgical table and end up in the sterile surgical field above the patient
5. Portal of entry	Cardiac surgery	Orthopedic surgery
6. Susceptible host	The surgical patient receiving implanted foreign materials	The surgical patient receiving implanted foreign materials

HCD, heater-cooler device; FAW, forced-air warming.

with CFW, a decrease of 34%. The pooled multicenter data showed a PJI rate of 1.69%, which decreased to 0.37% following the discontinuation of FAW and a switch to air-free CFW ($n=2034$; $P=0.002$).

Discussion

This is a multicenter observational outcome study investigating the possible relationship between FAW and PJI in hip and knee total joint replacement surgery. The data were collected retrospectively at three hospitals. The switch from FAW to air-free conductive fabric warming is the only independent variable identified during the study period. It is axiomatic that warming by convection is inefficient; resulting in the release of waste heat.²⁵ The most common brand of FAW was used by all three hospitals in this study. However, it must be noted that all other brands of FAW also release approximately the same amount of waste heat, thereby causing the same surgical contamination risks. The pooled multicenter data from the three hospitals reported in this study showed a decreased PJI rate of 78% following the discontinuation of FAW and a switch to air-free CFW. This pooled result corroborates the findings of the McGovern study, which reported a 74% decrease in PJI rates when FAW was discontinued and CFW was initiated.⁸ Assuming that there were no other unreported significant changes in the surgical or antibiotic protocols during the study period, the significant drop in the PJI rates must be attributed to the discontinuation of FAW until proven otherwise.

The suggestion that FAW could simultaneously be causing PJIs and reducing soft tissue SSIs seems to be contradictory. However, this apparent contradiction is explained by the presence or absence of biofilm.²⁶ Biofilm is a coating of exopolysaccharide material that protects the bacterium from antibodies and antibiotics, effectively allowing it to hibernate for up to one year before sprouting into a full infection. Many bacteria can form biofilm coatings in the presence of implanted foreign materials, but cannot form effective biofilm in soft tissue.²⁶ The result is that the infectious process is fundamentally different in joint replacement surgery, where a single bacterium can cause an infection, compared to soft tissue surgery, where an inoculum of more than one million bacteria is usually required to cause an infection.¹⁶⁻¹⁸ Patients receiving implants, especially orthopedic implants, are especially susceptible to infection because bacteria can form biofilm on the implant.

The often-referenced studies showing that FAW reduces SSIs were investigating soft tissue surgery (colon, breast and hernia), where effective biofilm cannot be formed.^{1,2} With soft tissue surgery, maintaining normothermia by any means of active warming seems to lower the infection rate. Even heavily contaminated air cannot introduce the inoculum of more than one million bacteria into a wound, the quantity required for a soft tissue infection. In contrast, the results of this study suggest that FAW should not be used during joint replacement surgery, where a single bacterium is adequate to cause the PJI.¹⁶⁻¹⁸

There is a striking similarity between the waste heat and air from HCD causing heart valve infections and the waste heat and air from FAW causing PJIs after hip and knee replacement surgery. Using the CDC's *chain of infection* methodology, the similarities between HCD infections and FAW infections can be appreciated (Table 2).

The similarity between these infections and the equipment causing them supports the CDC's broad recommendation to not use any equipment that blows air in the operating room. *Nothing that blows air should be in an operating theater; if possible and ...it is important not to blow air in the operating theater.*²⁴

In summary, seven published studies have documented the contamination of the sterile surgical field by the rising waste FAW heat.⁷⁻¹³ Now, there are two retrospective outcome studies investigating the linkage between the rising waste FAW heat and deep PJI in joint replacement surgery. Both of these studies show significant decreases in PJI rates when the use of FAW is discontinued. Discontinuing the use of FAW in this multicenter retrospective trial resulted in a reduction of the PJI rates of 78%, which is consistent with the 74% reduction reported by McGovern *et al.*⁸ In both of these studies, the lower infection rates were achieved while using air-free CFW.

According to the American Academy of Orthopedic Surgeons, the incidence of periprosthetic joint infection after primary hip or knee arthroplasty is over 2% among the Medicare population.²⁹ Therefore, the approximately one million of these procedures performed annually in the US should result in 20,000 PJIs per year. 20,000 catastrophic, permanently disabling PJI infections per year would seem to qualify as a public health crisis if they have a common etiology. This study suggests that more than 15,000 of these infections (78%) may be caused by FAW and are thus preventable.

Given the current FAW contamination and infection research and the CDC's recent admonition against blowing air in the oper-

ating room, it may be that a randomized controlled trial (RCT) would be unethical at this point. Therefore, retrospective outcome studies are the most robust clinical information that is likely to be available on this topic, and additional studies should be encouraged.

Conclusions

Based on these data it seems prudent that hospitals and clinicians avoid using forced-air warming on patients during surgeries involving implanted materials, especially joint replacements, until it is proven to be safe.

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