EVIDENCE IS INCONCLUSIVE THAT FORCED AIR WARMING DEVICES INCREASE SURGICAL SITE CONTAMINATION OR INFECTION

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Abstract

The greatest degree of heat loss in surgery is during the first hour after induction of general anesthesia. Intraoperative hypothermia poses great risks for the patients and their recovery. The use of forced air warming devices has been well studied and shown to maintain patient normothermia. There is concern that forced air warming disrupts operating room airflow and contaminates the sterile field leading to surgical site infections. A literature search was performed using Embase, Web of Science,

Clinical Key and Nursing at Ovid Joanna Briggs Institute (JBI). Five articles were found comparing the contamination risk of forced air warming with other warming technologies. The synthesis review found insufficient evidence to suggest delayed or discontinued use of forced air warming. The studies' lack of data showing patient surgical site contamination and inability to conclude that the forced air warming devices actually caused surgical site infections due to intraoperative contamination do not support a change to clinical practice. As the greatest amount of patient heat loss is during the first hour of anesthesia, the use of forced air warming devices at this time is supported as opposed to delaying use due to unsupported concerns of surgical site contamination.

Keywords
Forced air warming, intraoperative, contamination, infection, normothermia

Introduction

Hypothermia is an issue during the perioperative period and is caused by various factors. Anesthetics such as volatile agents, intravenous (IV) agents, and spinal/epidural anesthesia impair the patient's thermoregulation capabilities.[1] Within the first hour of administering anesthesia, the patient's core temperature drops significantly due to redistribution of body heat.[1] Core temperature redistribution is due to peripheral vasculature vasodilation and subsequent transfer of body heat to the environment. Radiation of body heat is the primary mechanism of heat loss followed by convection, conductance, and evaporation. As with all diffusions, the greater the difference in concentration, pressure, or heat energy, the greater the net movement. Peripheral vasodilation also increases the surface area exposure of body heat promoting net diffusion. Cold operating room (OR) temperatures, infusion of cold IV fluids and open body cavities contribute to heat loss experienced by the patient. Perioperative hypothermia is associated with postoperative mortality, bleeding,

platelet inhibition or dysfunction, shivering, and a decrease in neutrophil activity causing infections.[1] Active air warming is known to be superior to passive warming in preventing intraoperative hypothermia. Forced air warming (FAW) has shown to be most effective compared to other warming or heat conserving methods in maintaining core body temperatures, reduced shivering, reduced morbidity caused by infection and bleeding and shorter length of hospital stay overall.[1]

Evidence supports the use of FAW preoperatively and intraoperative, especially during the first hour after general anesthetic induction, a critical point of heat redistribution from the core body to the periphery. During this time, the surgical site is exposed and prepped for a sterile field. The OR air is prudently directional and filtered during surgery to prevent the contamination of sterile equipment and surgical sites. Unidirectional downward airflow is used in many operating suites, specifically orthopedic, to deter unwanted pathogens from surgical sites and sterile areas.[2] There is concern that FAW systems may increase the risk of infection by airborne-microbial emissions directly from the device or by disrupting laminar airflow in the OR.[2] Therefore, it is important to evaluate active warming devices to determine if one contributes to increased contamination. Does FAW, compared to other warming devices, increase intraoperative infection risks by interrupting OR ventilation and/or releasing microbial emissions resulting in a contaminated surgical site?

Methodology

A literature search was conducted using Embase including Medline, Web of Science™, Clinical Key and Nursing@Ovid (Joanna Briggs Institute) to find articles discussing intraoperative contamination possibilities of forced air warming systems and its counterparts. The keywords used were "forced air warming," "operating room*," "contamination" and "infection." Keywords were combined using OR and AND to limit the results. The final search was "(forced air warming) AND (operating room*) AND

(contamination OR infection)." Nine out of 16 articles found in EMBASE were relevant to the topic. Seven were excluded because they addressed only the use of an active warming device for the prevention of perioperative hypothermia and discussed the reason for laminar airflow and its proper use in the OR. Three additional studies were excluded because of unavailable data.

The Web of Science database provided 9 total articles using the same keywords; however, only 2 were unique. Four of the 9 were repeats from the previous EMBASE search, and 3 were excluded after reviewing the abstracts for relevance. In Clinical Key, a search using the terms yielded a total of 120 articles. After reviewing these abstracts, it was determined that there were no new articles. Two additional studies were obtained from the bibliographies of appropriate articles. A total of 10 articles were used for this review.

Literature Review

Legg et al compared two warming devices against a control of no warming device.[2] The devices, a FAW blanket (Bair Hugger™) and a radiant warming blanket (HotDog® were applied to a volunteer's torso.[2] The purpose of the study was to determine if these devices increased the temperature and the number of simulated bacterial particles present at the surgical site.[2] A controlled simulated operation was set up with one surgeon present in the theatre.[2] Temperature measurements were performed before and 30 minutes after warming and a HandiLaz® counter was used to count the number of particles.[2] The HandiLaz counter is a handheld device that measures particles in the air using laser and photo detector technology, the particles are counted and sorted according to size.[2] Each mode of measurement was repeated 5 times using each device and the control.[2] The operating theatre was unable to simulate a true surgical environment because it lacked the usual influence of equipment, personnel, and their movements during normal working conditions. Although the experiment resulted in a significant mean increase in temperature

(1.1°C vs. 0.4° C, $P<0.0001$) and concentration of particles (1,038.2 vs. 274.8, $P=0.0087$) when using a FAW device, conclusions cannot be made that this would cause an increased intraoperative risk of surgical site infections.[2]

A replicated full factorial design was performed by Belani et al to determine whether a FAW blanket (Bair Hugger™ Model 540; Arizant Heathcare) or a heat-conducting fabric blanket (HotDog® Model B110; Augustine Temperature Management) positioned over the torso disrupted ventilation in the OR causing surgical site contamination.[3] The conducting fabric was powered using low voltage electricity. Neutrally buoyant detergent bubbles, with a 4-mm average diameter, were produced using a generator specifically designed for the purpose of air current visualization.[3] An operative theatre was set up for a total knee replacement in an orthopedic OR with laminar downward ventilation airflow.[3] An anesthesia practitioner was placed at bedside with an anesthesia drape at high or low position. Neutrally buoyant bubbles, which simulate skin cell fragments and free-floating bacteria, were introduced at the head of the mannequin to track air movement under the sterile drape. Time-lapse photography was used at 10-second increments to measure bubbles present at the surgical site.[3] FAW had a large increase in bubbles measured at the surgical site compared to conduction fabric (132.5 vs. 0.48, $P=0.003$) and the controlled condition of no warming device (0.01, $P=0.008$).[3] Conduction fabric did not have a significant difference in bubble measurement compared to the control ($P=0.87$).[3] Although the simulation environment of this study found air current disruption with FAW a causation or correlation to surgical site contamination or infection is unable to be made. A conflict of interest existed with this study as the authors received research funding, consultant fees, and salary from Augustine Temperature Management, the company that manufactures the non-FAW device conductive fabric blanket used in the experiment.[3]

A simulation study by McGovern et al also used neutrally buoyant bubbles to identify disruption of airflow comparing a FAW device (Bair Hugger™ Model 540; Arizant Healthcare) and the HotDog™ conductive fabric blanket (Augustine Temperature Management).[4] This study found the similar results as Belani et al.[3] Of the two devices, the FAW device resulted in higher measurements of bubbles (68 vs. 0, $P< 0.001$) in the simulated surgical site area of the mannequin. In addition, this study included retrospective collection of data from joint replacement surgeries during a 2.5 year period.[4] Data included infections that presented within 6 months after surgery. The study found that 1,066 patients had surgery using the FAW device and 371 used the conductive fabric.[4] A higher incidences of joint infections was found when FAW was used (odds ratio 3.8, $P=0.024$) and a significant reduction in infection rates was found with conductive fabric versus FAW (0.8% vs. 3.1%, $P=0.024$).[4] The major weakness in the joint infection data collection was that the prophylactic antibiotic regimen changed multiple times over the 2.5 year time period.[4] Incomplete recording of important predictors of deep infections such as blood transfusions, obesity incontinence and patient fitness level before surgery further weaken the study. This is the first evidence found that links (albeit weakly) FAW to surgical site infections.

Sessler et al conducted a study in 2011 using FAW in a two separate simulated OR environment to determine disruption of air quality. The Bair Hugger™ FAW model 522 upper body blanket and model 635 under- body blanket were tested in three conditions: baseline with the blowers off, blowers on with cool ambient air, and blowers on with heat.[5] A conscious volunteer was positioned on the OR table and 6 heated mannequins were positioned around the OR to simulate OR personnel. The use of nonmoving heated mannequins allowed convection currents but prevented airflow disturbance by human movement in an effort to isolate FAW airflow disruption.

A particle detector was placed over the volunteer's abdomen and a vapor generator allowed for visualization of airflow.[5] The equation for the log reduction of particle concentration at the test point in relation to the particle load in the room was $PE_x = -\log(C_x/C_{ref})$.[5] Log reduction of 2.0 was indicated as the threshold minimum value by Deutsches Institut für Normung (DIN) standards developed in Germany to calculate the function of laminar airflow. The worst of 5 measurements were calculated for each device. By comparing the 3 different testing conditions to the baseline particle load in the OR, FAW was found to have no compromising effect on laminar airflow (3- to 5-log reduction).[5] A supporting author of the study received research funding from Arizant Healthcare, manufacturer of Bair Hugger.[5]

In 2011, Albrecht et al evaluated the Bair Hugger model 505 and included the evaluation of 2 generations of intake filters by the same manufacturer, the newest 200708D model, and the current 200708C model.[6] Five of each filter model were tested according to industry standards using a sodium chloride aerosol.[6] Fifty-two of the FAW models used in real OR settings were assessed for intake filter retention efficiency, performance in the OR, FAW blower-generated particles, and air path microbial colonization of the internal distal hose.[6]

The newer model filter's efficiency was lower than that of the current model, resulting in FAW blower contamination emissions of 61.3% vs. 93.8%.[6] Buildup of internal airborne contamination largely depends on the environment in which the device is used; 58% of the 52 blowers from 11 hospitals produced contaminants.[6] This was the first study to evaluate the relationship of intake filter performance with FAW blower contamination. Microbial-contaminated emissions in the OR are a potential clinical risk.

Recently, Reed joined the authors of the Belani et al[3] study and conducted a similar experiment on the most current and widely

used FAW device. The Bair Hugger FAW model 750 was evaluated on four categories: intake filter efficiency, intake filter performance in the OR, production of airborne contaminates, and internal air path microbial colonization.[7] We tested the intake filter's efficiency by counting sodium chloride particles the filter captured during a 10-minute challenge.[7] Laser particle counts were calculated from 23 FAW blowers after hours in the OR of a hospital to test the filters' efficiencies.[7] We replaced the filters on the same 23 FAW devices, measured the particle counts downstream, and obtained swabs from the internal air path surfaces to determine contamination emission and microbial colonization.[7]

The filter challenge revealed only 63.8% efficiency and, by removing and challenging all 23 intake filters, it found only minute differences in filtration efficiency and showed that the intake filters were performing to specifications in the OR.[7] Furthermore, 96% of the FAW devices produced contamination emissions, and 100% revealed the presence of microorganisms from the distal end of the blower.[7] The study found that FAW devices inadequately filter particles, allowing microbial colonization distal to the filter.

In a nonrandomized comparison study, Dasari et al compared the temperature warming effects of the Bair Hugger, an underbody resistive mattress (Inditherm™, Inditherm Medical, Rotherham, UK), and the HotDog conductive fabric system.[8] The hypothesis was that increased temperatures caused by warming systems can disrupt laminar flow ventilation by creating convection currents at the surgical site. To test this hypothesis, warming devices were placed on the lower body of a mannequin, and temperature measurements were recorded in 60-second intervals using 24 thermostats at various heights above the OR table.[8] In an environment simulating an orthopedic OR, temperatures were measured during 3 distinct periods over 5 different areas of the mannequin: the right and left shoulder, abdominal area, and right and left knee.[8] The "control" time was the 20-minute period

before warming, the "transition" was the 10-minute period after the device turned on, and the "steady state" was the 20-minute period after the device was turned on, when the device had thermally balanced.[8] This technique was performed for each device.

The data was used in an analysis of variance model to formulate results.[8] FAW caused the greatest temperature increase from the control period versus the conductive blanket (+2.73 (0.7)°C; $P<0.001$) or resistive mattress (+3.63 (0.7)°C; $P<0.001$) at the mannequin's abdominal surgical site.[8] At shoulder level, there was no significant difference in temperature among any of the devices.[8] The effect of increased heat at the surgical site in terms of infection remains unknown.

Huang et al conducted an experiment during 16 abdominal vascular prosthetic graft insertion procedures using Bair Hugger FAW systems.[9] Bacterial counts in the air and wound specimens were collected and compared at the start and end of surgery.[9] The mean number of colonies of microbial growth from the OR air and the exhaust fan near the axillae of the patient decreased from the start of the operation to the end (mean reduction, 36.4%; $P<0.01$).[9] These results could have been due to the movement of OR staff and turbulent air circulation at the beginning of the procedure compared with the end. A 6-month follow-up visit confirmed that no patients experienced postoperative or graft infections during that time.[9] The author concluded the Bair Hugger did not contribute to bacterial contamination of the operating environment or the surgical field.[9]

Moretti et al conducted a study similar to Huang in that microbial samples were collected on agar plates using the Active Surface Air System in the OR of a procedure instead of a simulated environment. Samples were collected in 3 different points: A1, A2, and A3, around the operating table in the empty OR immediately before surgery, when the patient arrived, and when FAW was applied.[10] Twenty noncemented hip implantations

were performed; no patient had postoperative hypothermia-associated complications or surgical infection in a 6-month period.[10] However, a significant bacterial load was observed after the patient was placed on the OR table and FAW was applied (A1=17.8±14.5 vs. 79.2± 52.2 cfu/m^3, $P<0.001$; A2=19.4±17.5 vs. 61.2±38.8 cfu/m^3, $P<0.001$; A3=19.2±17.7 vs. 69.1±56.8 cfu/m^3, $P<0.001$).[10] The results are not quantifiable but suggest that FAW does not contaminate the surgical field. Medical staff and movement in the OR better explain the significant increase in bacteria colonization.

In 1997, Avidan et al conducted four experiments using 10 FAW devices (9 Bair Huggers, Augustine Medical [now 3M], and 1 Warm Touch [Mallinckrodt Medical, St. Louis, MO]).[11] The first specimens were collected from the airflow of 10 blowers using agar plates on sterile towels in an unused OR.[11] Control plates were used during the 5-minute intervals between turning on the blowers.[11] Four the 10 (40%) agar plates grew organisms, including *Staphylococcus epidermidis*, *Corynebacterium*, and *Cryptococcus albidus*.[11]

The second experiment sought to determine if blowing warm air through a perforated blanket reduced microbial contamination. The plates were placed below the blankets for 30 minutes with the blower on, and control plates were collected for the same time with the blowers off.[11] Neither the control nor the experimental plates grew organisms.[11] Next, we used sterile swabs to collect samples from both sides of the internal filter and the inside of the proximal and distal end of the hose. The inside of the internal filter lacked growth, while the outside grew organisms such as *Aspergillis fumigatus* and *Bacillus* sp; both the proximal and distal hose swabs had similar growth.[11] The final experiment consisted of comparing the microbial growth of the direct airstream from three blowers—with and without an attached microbial filter at the distal end of the hose. The microbial filter prevented growth after it was applied to the same blowers that

grew *Acinetobacter lwoffii* and *Staphylococcus epidermidis* on the plates placed directly in the airstream of the warmers.[11] The author states that, after this study, their hospital facility changed its policy to require the attachment of a perforated blanket when using FAW in the OR.

Synthesis

Studies in this review compared airflow disruption and microbial contamination of FAW with that of other warming devices to identify infection risk associated with these devices. Ten of the studies [2-8,11] were experimental designs, 2 involved human subjects,[9,10] and 1 included retrospective hospital surgical infection rates.[4] Although the studies by Albrecht, Reed, and Huang found that microbial contaminates may be present in FAW device hoses, its clinical significance has been questioned by the lack of data showing surgical site contamination, causative increased infection rates, and a specific study that showed that, despite microbial presence at the FAW device distal hose, no air contamination from the perforated warming blanket required for patient use was found.[11] Only a retrospective study found an increased infection rate over a 2.5-year period when FAW devices were used versus a convection device, but the causative variables were not isolated, and prophylactic antibiotic regimens were not controlled. Considering that high-efficiency particulate air filtration improves microbial entrapment and that microbial growth on FAW device hoses occurs, regular changing of FAW device filters may be beneficial but cannot be recommended. Hose decontamination is also a consideration, but further study is necessary to determine its efficacy. Randomized controlled studies in multiple facilities comparing FAW and other patient-warming devices should collect data on surgical site or implant infection rates and correlate it with the causative pathogen.

Conclusion

The studies in this review primarily focused on the disruption of OR airflow and microbial contamination and emissions

of FAW devices and could only infer potential effect on surgical site contamination. No studies have demonstrated that FAW contributes to a greater risk of surgical site infection. In addition, most studies were funded or conducted by researchers affiliated with two competing device manufactures, introducing bias. The clinical decision to avoid FAW during the immediate period after induction of anesthesia and during surgical prep must be weighed against the well-documented risk of core temperature redistribution, which is at its worse during this time.

Warming of the patient during the first hour of anesthesia is important, and maintenance of normothermia has become a standard of practice. Hypothermia has been associated with increased infection rates.[15] This review found limited data to support limiting FAW perioperatively. If FAW is the only method available to maintain patient temperature, its avoidance at the beginning of the operative period is not advised. If other warming methods are available and effective, they may be substituted. Evidence does not support terminating the use of FAW in the OR environment, nor does it support delaying the use of FAW until surgical drapes are placed. Because it may take as long as an hour to prepare and drape a patient for surgery, the heat loss during this time can be significant. Until definitive evidence is found to advise otherwise, the use of warming devices, including FAW, is recommended without change from current practice.

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