Can Efficient Smoke Evacuation Limit Aerosolization of Bacteria?

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ABSTRACT

Preventing surgical site infections requires knowledge of the sources of wound contamination. One possible source of wound contamination is bacteria aerosolized in diathermy plume (ie, surgical smoke). This study used an experimental model of porcine tissue embedded with *Serratia marcescens* to determine the extent of viable bacteria present in surgical plume. The results showed that only blended current electrosurgery, not laser plume or coagulation electrosurgery, contains viable bacteria. Further, the study revealed that placing a suction device near the electrosurgical site reduced the number of aerosolized viable bacteria. Therefore, evacuating the electrosurgical plume may help reduce contamination of the surgical wound. Nurses may wish to advocate for the use of air suction devices as one way to protect patients from surgical site infections. *AORN J 102 (July 2015) 7-14. © AORN, Inc, 2015. http://dx.doi.org/10.1016/j.aorn.2015.04.023*

Key words: *diathermy plume, electrosurgical smoke, surgical site infections, surgical smoke evacuation, bacterial aerosols.*

Surgical site infections (SSIs) are the second leading cause of health care–associated infections (HAIs).[1] Many attempts at prevention have been evaluated,[2] such as preoperative bathing,[3] various times for hair removal or not at all,[4] chemicals for surgical hand antisepsis,[5] different antibiotic protocols,[6] and controlled airflow in the OR.[7] Despite these efforts, preventing the first step in infection, that of contamination, remains elusive. One obvious possibility of a source of wound contamination is diathermy plume (ie, surgical smoke), which is common to most surgeries. Surgical plume is defined as the bioaerosol created by electrosurgery, lasers, and high-powered drills and saws. Surgical plume has been shown to contain live viruses and bacteria,[8,9] toxic chemicals,[10] and particulates,[11] as well as the patient's own potentially contaminated body fluid in the form of blood and vapor.[12] If surgical plume serves as a transfer vehicle for bacteria, then effective prevention could potentially lessen the economic impact of SSIs.

STATEMENT OF PURPOSE

This study sought to determine the extent to which live bacteria exist in surgical plume and whether that bacteria can contaminate the wound margins or through aerosolization disperse the bacteria to areas beyond the wound. Further, can the contamination be eliminated or significantly lessened by effective capture of the plume, thereby preventing the occurrence of SSIs?

RESEARCH QUESTION/HYPOTHESIS

To fulfill the purpose of this research, an independent third-party team of bacteriology experts developed a laboratory model that allowed live bacteria to consistently exist in surgical plume. After they created that model, the team worked to answer the following question: Could such bacteria be made to disperse and aerosolize in surgical plume? Finally, if they determined that the model caused such dispersal, the team needed to answer another question: Could the use of a smoke capture and evacuation system capable of documented 98% to 100% smoke capture efficiency prevent or significantly decrease such dispersal?

STATEMENT OF SIGNIFICANCE TO NURSING

Nanoparticles that comprise 80% of surgical plume (L Schultz, unpublished data, 2013) can cross the alveolar membrane and

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proceed to distant internal sites and become associated with multiple systemic diseases.[13] The ability to capture surgical plume effectively suggests the potential benefit to patients by reducing the chance for wound contamination.

LITERATURE REVIEW

Surgical site infections impose a staggering cost to our economy and to patients. Estimates for the treatment of SSIs in the United States average $25,546 per patient,[14] for a total cost approaching $1.6 billion annually.[15] A recent study cited the cost of HAIs as $147 billion annually in both the total cost of all HAIs, which includes causes such as catheter infections, sepsis, pneumonia, and urinary tract infections, as well as SSIs annually in both

- direct costs (eg, buildings, consultations, devices, equipment/technology, food, labor [eg, laundry, environmental control, administration], medications, procedures, supplies, testing [eg, laboratory, radiographic], utilities) and
- indirect costs (eg, home care costs, forgone leisure time, lost or diminished wages and worker productivity on the job for the patient and family members, morbidity [ie, both short-term and long-term], mortality, travel costs, wasted time spent by family and friends for hospital visits).

Costs related to direct care of HAI's approached $45 billion per year.[16]

Causes of SSIs

Multiple contributory causes of SSIs have been identified. These causes include

- a source for bacteria from a remote site in the patient (eg, lungs, urinary tract),[17]
- vascular catheter contamination,[18]
- malnutrition,[19] or
- a compromised immune system.[20]

The first two causes require seeding of bacteria from a remote site to the wound. Direct contamination of the wound also may occur in cases of intra-abdominal infection or bowel resection. In general, the most useful practice to reduce wound infection rates is to use laparoscopy, in which manipulations are accomplished through a trocar, or to place a protective barrier over the exposed wound margins. Both of these methods suggest the need for protection of open wound margins with a nonporous barrier. Two studies demonstrated decreased infection rates when plastic barriers (eg, trocars used during laparoscopy,[21] nonporous sheets used during open surgery[22]) were used to protect the wound opening from airborne contamination and manipulation of the wound that occurs by hand and with surgical instruments.

To make SSI prevention even more difficult, modern surgical techniques, improved home care, high inpatient costs, and new third-party payer rules contribute to the early discharge of patients, which may result in delayed recognition of infection.[23] Previously, in-hospital observation of the early signs of contamination (eg, small increases in body temperature, wound erythema) led to a prompt evacuation of wound fluid with rapid resolution of the potential infection. Warm compresses were used; if no antibiotics were administered postoperatively and if the expressed fluid grew a specific bacteria, antibiotics were then administered, but not without culture results. Debridement was not needed unless the wound was necrotizing, which was very rare. This recognition may now be delayed until the patient returns to the surgeon's office for a one- to two-week postoperative visit or until the infection is advanced enough (eg, fever, pain, suppuration) to alert the patient or his or her caregivers to the infection.

> "Modern surgical techniques, improved home care, high inpatient costs, and new third-party payer rules contribute to the early discharge of patients, which may result in delayed recognition of infection."

Often, hospitalization is required for the patient to undergo a costly, complex treatment regimen should a wound infection

be diagnosed that is far along in the process. Such costs are now being borne by the hospital and the health care practitioners because of a 2010 ruling by the Department of Health and Human Services, which no longer allows payment for complications for which readmission occurs within 30 days of original discharge.[24] The need to determine the initiating cause and identify a method of preventing wound infection is now a major priority for all health care facilities and practitioners because such additional cost burdens could prevent hospitals from providing sustained community care. If a major contributory cause, such as surgical plume serving as the transfer vehicle for bacteria, is delineated, then effective prevention could lessen the economic impact of SSIs.

METHODS AND MATERIALS

An independent third-party team of bacteriology experts at Biotest Laboratories, Inc, Brooklyn Park, Minnesota, a subsidiary of Steris Corporation, Mentor, Ohio, independently developed the protocol, performance of the experiments, and tabulation of the results in response to questions given to them by the author. A series of three experiments was performed.

- In the first experiment, they developed the model that allowed bacteria to aerosolize from the target tissue (ie, porcine skin and fat) after vaporization with blended electrosurgery current.
- The second experiment was used to determine whether the carbon dioxide (CO_2) laser could duplicate the bacterial dispersion.
- In the third experiment, they compared the effects of coagulation and blended electric current, with and without suction, on bacterial aerosolization.

Serratia marcescens (ATCC 3880 lot number 247-26-4) was selected as the test bacteria for these experiments. The initial population was 1.7×10^{10} colony-forming units (CFU)/0.1 mL, which was prepared as a suspension to a concentration of approximately 2.4×10^{2} CFU/0.1 mL. The test tissue was a 3-oz segment of porcine skin and fat that had been irradiated with a gamma dose of 10.9 to 13.5 kilogray to achieve sterility.

Culture plates were made for air sampling from trypticase soybean agar and the culture plates used for wall and floor sampling of the enclosure as well as media plates from trypticase soybean agar and lecithin polysorbate 80. This was added to offset possible growth inhibition by the sodium hypochlorite solution that they used to clean the enclosure surfaces. The culture and media plates were placed at four quadrants around the target tissue.

All experiments were performed in a polymethyl methacrylate (ie, transparent thermoplastic) enclosure, henceforth referred to as the "glove box," which measured 30" wide by 48" long by 30" high. One end of the long axis of the box had a loading air lock, which measured 12" wide by 14" long by 12" high. The air lock was separated from the glove box by a partition, which they opened to the box after they closed the door to the outside air. Sterile gloves were worn so that they could transfer the material aseptically from the air lock to the box and also maintain an aseptic environment within the chamber.

The following pieces of equipment were used for the experiments:

- Mega Power® Electrosurgical Generator, S/N 13910001, Ref. 1000, from Megadyne, Draper, Utah;
- Sharplan CO_2 Laser (model #1030) from Sharplan, Newport, Australia;
- PureVac™ Turbo Smoke Evacuator System (model #906150) with a ULPA-Clear™ filter (part #901301) from Surgimedics, San Antonio, Texas; and
- miniSQUAIR® Surgical Smoke Evacuation System (part #SQ20012-01, lot #04151304) and SQUAIR® Small Capture Device (model #200-000-001, lot #04281104) from Nascent Surgical, LLC, Eden Prairie, Minnesota.

Experiment 1

For the initial microorganism dispersal study, the researchers used the glove box after its interior was cleaned with sterile, low-lint wipes impregnated with a sporicidal solution of 1:50 sodium hypochlorite. All required media plates were passed from the air lock to the enclosure to maintain sterility. This included the

- air impact plates and the M Air T® air sampler impact device (Millipore Filter Corporation, Bedford, Massachusetts),
- sterile instruments and bacteria container with micropipettes and tips for seeding the bacteria on the porcine tissue,
- sterile monopolar electrode,
- sterile towels, and
- sterile capture devices.

The electrode wire, electrosurgical unit dispersive pad, and capture device tubing were passed out of the enclosure to their external connections through small side holes in the back wall, with the holes then closed over with tape to preserve isolation of the box contents. Four high-efficiency particulate air filters exited the top of the enclosure at its corners to allow air to enter the box when suction was applied.

Sterile towels were moistened with sterile saline and used them to create a basin 2 inches high with the electrosurgical unit dispersive pad at its base and the tissue placed over the dispersive pad. The RODAC™ (Replicate Organism

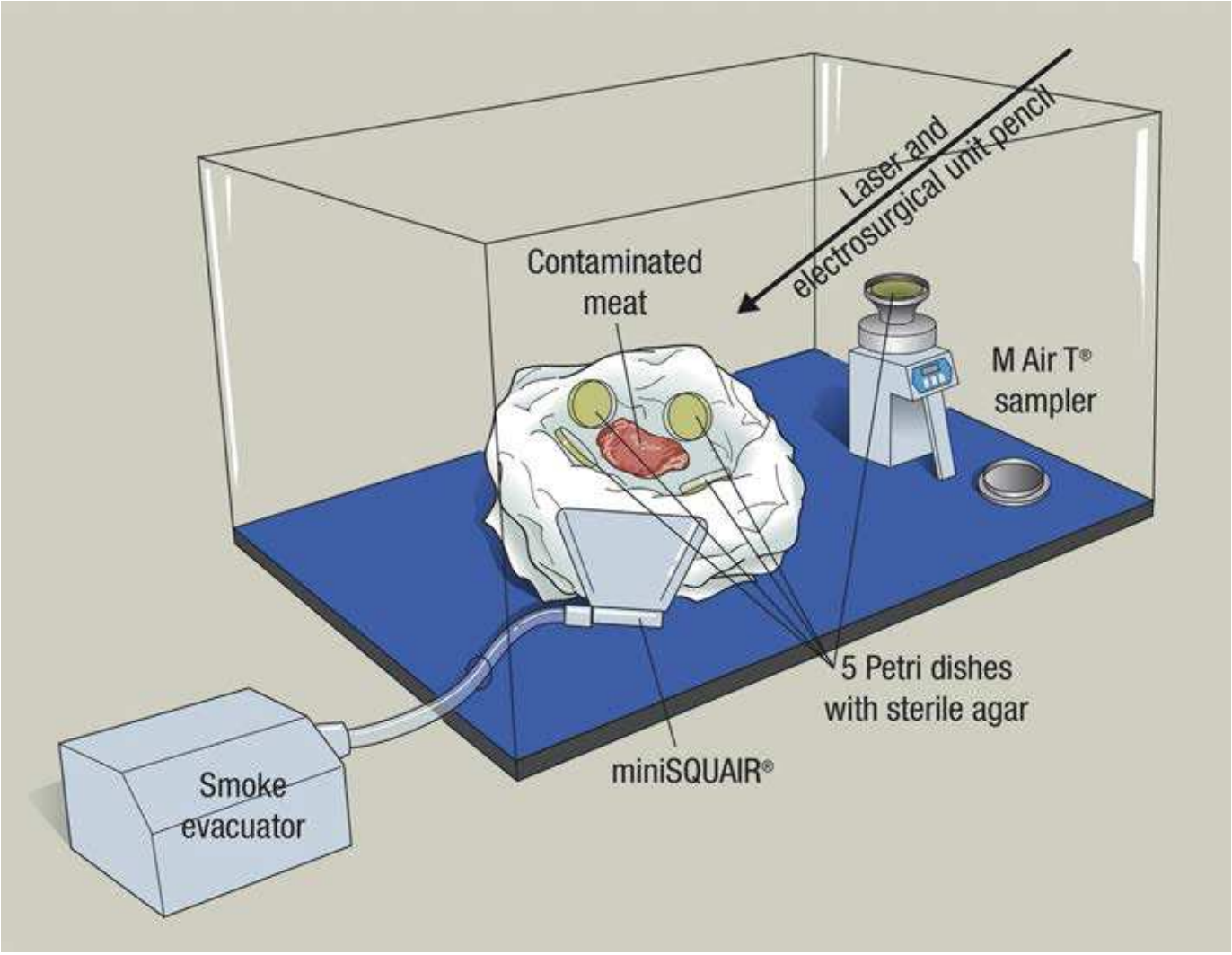

Figure 1. Illustration of the transparent thermoplastic enclosure (ie, glove box). The porcine tissue embedded with *Serratia marcescens* is in the center of the well, surrounded in four quadrants by sterile RODAC™ agar-filled plates. The M Air T® air sampler in the right side of the box has a sterile RODAC plate on its top to sample any air or smoke present in the box. (*M Air T is a registered trademark of Millipore Filter Corporation, Bedford, MA. RODAC is a trademark of Becton, Dickinson and Company, Franklin Lakes, NJ.)*

Detection and Counting) media plates (Becton, Dickinson and Company, Franklin Lakes, New Jersey) was placed 1 to 2 inches from and at four quadrants around the tissue leaning up against the towels (Figure 1). One air sampling plate was placed within the M Air T air sampler impact device, which was 2.5 feet from the target tissue.

The *Serratia marcescens* suspension was mixed, previously prepared with *Pseudomonas* isolation agar to ensure a known population, by vortexing for a minimum of 30 seconds and micropipetting 0.1 mL onto the meat surface. This was then allowed to stand for five minutes.

The electrosurgical generator was activated with a foot switch and applied the electrode's blade to the impregnated meat continuously for 90 seconds. Settings included coagulation at 220 watts and cutting/blend at 220 watts. Surgical plume was allowed to permeate the chamber for each setting and set the air sampler intake at 300 L/min. Before and after completion of the two electrosurgical periods, they collected the plates and cultured them under standard conditions at 25° C (77° F) for three days before calculating colony counts.

Experiment 2

The researchers used the same methods and materials as in experiment 1, except that the Sharplan CO_2 laser, set at 20 watts pulsed mode, was used at 30 and 60 seconds. Samples were taken at these intervals with and without the use of capture devices attached to suction using an ultra-low

Table 1. Tabulated Results of Experiment 1: Colony-Forming Units Present

	Sample Designation	Colony-Forming Units of *Serratia marcescens* Present
Baseline (before inoculation and cauterization)	5	0
	6	0
	7	0
	8	0
Blended cutting mode	1A	0
	2A	4
	3A	8
	4A	0
Coagulation mode	1B	0
Coagulation mode	2B	0

particulate air filter and 45 cubic feet per minute airflow. The capture devices were placed on the rim of the towel basin with the attached suction turned on during the entire period of vaporization.

Experiment 3

The researchers used the same methods and materials as in experiment 1 in all aspects except that they used SQUAIR and miniSQUAIR capture devices on suction with their placement the same as seen in Figure 1. Only electrosurgery was used because lasing in experiment 2 failed to show any dispersion of bacteria.

RESULTS

The results of experiment 1, tabulated in Table 1, indicated that viable bacteria were present on plates 2 and 3, which they had placed in quadrants around the tissue vaporized with a cutting blended current. Viable bacteria were not present when coagulation alone was used. No colonies grew on the walls or floor of the glove box or in the air sampler. The results of experiment 2, tabulated in Table 2, indicate that no growth of viable bacteria was present at any site at any period of time after lasing. The results of experiment 3, tabulated in Table 3, show extensive bacterial growth in the Petri dish placed on top of the air sampler and decreased colonies in two of the four-quadrant Petri dishes. Plates 1 and 2 were far enough away from the SQUAIR and miniSQUAIR suction devices so that no protection against contamination was afforded these Petri dish sites. Protection was afforded only those sites (eg, plates 3 and 4) that were close to the miniSQUAIR and SQUAIR devices. Distance from the suction source no doubt played a role in these results.

DISCUSSION

The results indicate that live bacteria can exist in surgical plume that is produced with a blended electrosurgical current but not with the CO_2 laser or with pure coagulation electrosurgery at designated power settings. Previous studies have shown the laser's ability to sterilize contaminated wounds,[25,26] suggesting that the degree of heat transfer at higher temperatures determines the viability of bacteria that are exposed to the device. The culture results suggest that contamination of unprotected simulated wound margins can occur. Further, while such contamination can be significantly lessened with the use of high-efficiency smoke capture devices that are powered by effective suction, contamination cannot be prevented with current technology. Aerosolization of bacteria, however, can be prevented by such methods. Further, such aerosolization suggests a possible method for contamination of OR surfaces far from the operative site.

Table 2. Tabulated Results of Experiment 2—No Growth on Laser-Produced Samples

	Colony-Forming Units Present (ie, Growth)								
	T = 0 Seconds			T = 30 Seconds			T = 60 Seconds		
Test setup	RODAC™ Plates	Air Samples	Tissue Samples[a]	RODAC Plates	Air Samples	Tissue Samples[a]	RODAC Plates	Air Samples	Tissue Samples[a]
SQUAIR® Small Capture Device	0	0	<2	0	0	<2	0	0	<2
miniSQUAIR® Surgical Smoke Evacuation System	0	0	<2	0	0	<2	0	0	<2
No device	0	0	<2	0	0	<2	0	0	<2

The miniSQUAIR and SQUAIR are registered trademarks of Nascent Surgical LLC, Eden Prairie, Minnesota. RODAC is a trademark of Becton, Dickinson and Company, Franklin Lakes, New Jersey.

[a] *Sample with "<" sign indicates 0 colony-forming units were recovered. The stated value reflects the correction factor used during the testing.*

Table 3. Tabulated Results of Experiment 3—Effectiveness of Tools to Prevent Aerosolization

Sample Designation	Colony-Forming Units Recovered				
	Baseline Testing: No Device, No Smoke Generation	SQUAIR® Small Capture Device With Smoke Generation	miniSQUAIR® Surgical Smoke Evacuation System With Smoke Generation, First Trial	miniSQUAIR Surgical Smoke Evacuation System With Smoke Generation, Second Trial	No Device, Smoke Generation
	Air impact plates	Air impact plates	Air impact plates	Air impact plates	Air impact plates
1	0	0	0	0	TNTC[a]
	RODAC™ plates surrounding tissue	RODAC plates surrounding tissue	RODAC plates surrounding tissue	RODAC plates surrounding tissue	RODAC plates surrounding tissue
Tray 1	0	15	37	127	67
Tray 2	0	43	103	183	21
Tray 3	0	19	15	2	32
Tray 4	0	54	22	12	41
Average	0.0	32.8	44.3	81.0	40.3
	RODAC plates used to test walls and floor	RODAC plates used to test walls and floor	RODAC plates used to test walls and floor	RODAC plates used to test walls and floor	RODAC plates used to test walls and floor
Side 1	0	0	0	0	0
Side 2	0	0	0	0	0
Side 3	0	0	0	0	0
Side 4	0	0	0	0	0
Side 5	0	0	0	0	15
Average	0	0	0	0	3

The miniSQUAIR and SQUAIR are registered trademarks of Nascent Surgical LLC, Eden Prairie, Minnesota. RODAC is a trademark of Becton, Dickinson and Company, Franklin Lakes, New Jersey.

[a] TNTC (ie, too numerous to count) is any count greater than 300 colony-forming units for this size plate. The count has been estimated at 463 colony-forming units.

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The data in this study indicate that the miniSQUAIR, because of its high capture efficiency of 99.5%, is potentially capable of preventing contaminated surgical plume from contacting material surfaces while still arguing for a direct covering of exposed wound margins during open surgery (L Schultz, unpublished data, 2013). The results of experiment 3 show the effectiveness of blended current to disperse the bacteria and the effectiveness of capture-suction technology to prevent bacterial aerosolization and to decrease contamination in areas closest to the capture devices. This technology may now be considered as a potentially beneficial method of infection control in the OR.

STUDY LIMITATIONS

The primary limitation of the study is that it is a laboratory simulation without inclusion of clinical material. Whether the glove box mirrors a surgical field is beyond the scope of this study.

RECOMMENDATIONS FOR CLINICAL PRACTICE

The literature review and the study results provide validation and strong reasons for including routine smoke evacuation in surgical practice. The ability of evacuation to prevent bacterial aerosolization and to diminish local dispersal suggests a vital potential protection for the surgical patient.

RECOMMENDATIONS FOR FUTURE RESEARCH

The next logical step would be to perform a double-blind study to determine the effect of high-efficiency smoke capture on the

KEY TAKEAWAYS FOR CLINICAL PRACTICE

Can Efficient Smoke Evacuation Limit Aerosolization of Bacteria?

WHY DID WE DO THIS RESEARCH?

- This project was undertaken to discover if effective smoke capture could prevent bacteria-laden surgical plume from being aerosolized.

WHAT DID WE FIND?

- Effective smoke capture does prevent bacteria in smoke from being aerosolized.
- It also significantly reduces contamination of a simulated surgical wound by as much as 50% to 60% in contrast to control.

HOW CAN CLINICIANS USE THESE RESULTS?

- **Clinician:** Perioperative team members should consider using smoke capture devices routinely for open wounds as a possible method of reducing surgical site infections.
- **Manager:** Managers should use this information as well as other evidence-based research results to help evaluate newer methods of smoke capture and evacuation and to produce and implement a smoke evacuation policy in the OR to provide greater safety for the patients they serve and to protect the short-term and long-term health of perioperative team members.
- **Educator:** Educators should instruct personnel on how to use newer methods of smoke capture to help limit dispersal of bacteria-laden smoke throughout the operating suite and potentially reduce the rate of surgical site infections.

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rate of SSIs in a variety of surgical specialties. The potential savings to the nation's health care bill should add impetus to the initiation of such a clinical study. Aside from the clinical studies that could proceed from this research, the model could be used for studying the viability and dispersal of viruses and other bacterial entities after exposure to various surgical instruments such as bipolar cautery and harmonic energy.

Other studies that could extend from the observation that effective smoke evacuation can limit aerosolization of bacteria could be those of OR surfaces after use of such technology in open surgical procedures. An ultimate question needs to be answered: If contamination were decreased or eliminated, what effect would that have on the cost of infection control materials and practices?

CONCLUSION

Standard bacteriological methods have been used to establish a laboratory model that allows live bacteria to exist in surgical plume. That model was used to show that effective smoke capture and evacuation can limit local dispersal and aerosolization of the bacteria tested. The effect that such smoke removal may have on the infection rate of open surgical wounds is yet to be determined.

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