The Mutagenicity of Electrocautery Smoke

John E. Gatti, M.D., Charles J. Bryant, C.I.H., R. Barrett Noone, M.D., and J. Brien Murphy, M.D.

Camden, N.J., Bryn Mawr, Pa., and Cincinnati, Ohio

Careful analysis of electrocautery smoke produced during breast surgery has found organic compounds that are unidentifiable with current analytical techniques. The purpose of this study was to determine the potential mutagenicity of the smoke produced by the electrocautery knife during reduction mammaplasty. Multiple air samples were collected in the operating room during two reduction mammaplasty procedures. Airborne smoke particles were tested for mutagenic potential in both tester strains of *Salmonella typhimurium* (TA98 and TA100) using the standard *Salmonella* microsomal test (Ames test). All testing was performed by the Hazard Evaluations and Technical Assistance Branch of the National Institute of Occupational Safety and Health.

The smoke produced with the electrocautery knife during reduction mammaplasty was found to be mutagenic to the TA98 strain. The Ames test, an established technique for evaluating the mutagenicity of a substance, was convincingly positive for the smoke collected during the breast surgery. Whether the smoke represents a serious health risk to operating room personnel is not known. Development of techniques to limit electrocautery smoke exposure in the operating room appears to be needed, and surgeons should attempt to minimize their exposure.

Occupational hazards of health care workers have recently received a great deal of attention. Understandably, exposure to contagious diseases from contact with infected patients has generated the most interest. The operating room can no longer be considered a safe, secure environment for the health care worker. An increased awareness of the potential health risks to the operating room team is needed.

Most airborne particles are not effectively filtered or evacuated by present operating room equipment. Surgical masks filter only large airborne particles; evacuation and laminar airflow systems are employed sporadically. Safety efforts have been limited to reducing anesthetic gas exposure. Little energy has been directed toward identifying and limiting ambient health risks to the operating room team.

Visible smoke is produced when the electrocautery knife is employed for tissue dissection and vessel cauterization. The smoke can have a noxious odor and can often be a source of irritation to the surgeon and surgical assistants. Little is known about the composition of the smoke produced by the electrocautery. A previous study failed to identify known carcinogens in the smoke. However, the majority of the smoke produced by the electrocautery knife during reduction mammaplasty is unidentifiable by present analytical techniques.[1]

Reduction mammaplasty has become one of the more common surgical procedures performed by plastic surgeons, with a recent estimate placed at 35,000 yearly. Use of the electrocautery knife for breast tissue dissection and vessel hemostasis has become popular. Should the smoke produced by the electrocautery knife contain potentially harmful elements, a health risk to a large number of health care workers may exist.

A request was made to the Hazard Evaluations and Technical Assistance Branch of the National Institute of Occupational Safety and Health (NIOSH) for an evaluation of the smoke exposure risk to operating room personnel. This report concerns the on-site evaluation by NIOSH of the mutagenic potential of the smoke produced by the electrocautery knife during routine reduction mammaplasty.

Materials and Methods

Multiple air samples were collected in the operating room during two routine reduction

From the Divisions of Plastic Surgery at the West Jersey Health System, the Bryn Mawr Hospital, and the National Institute of Occupational Safety and Health. Received for publication October 26, 1990; revised May 13, 1991.

Presented at the 59th Annual Meeting of the American Society of Plastic and Reconstructive Surgeons, in Boston, Massachusetts, in 1990.

mammaplasties in which the electrocautery knife was used exclusively for breast tissue dissection and excision. The inferior pedicle technique was employed to support the nipple-areola complex. Injection of the breast tissue with an epinephrine solution was not done. The ages of the two patients were 51 and 16 years, respectively. Both procedures and on-site testing were performed at the Bryn Mawr Hospital.

Air samples were collected and analyzed by the Hazard Evaluations and Technical Assistance Branch of NIOSH. Technical information regarding the testing and results of these studies are available in NIOSH Report No. HETA 85-126.[2]

Sample Collection and Extraction

Airborne particles were collected on glass-fiber filters (type A/E, 4-in diameter) using Hi-Vol pumps (General Metal Works, Cleves, Ohio 45002) at flow rates between 17 and 24 ft^3/min. Filters were changed if the flow dropped below 17 ft^3/min.

Samples from the first patient were extracted with 150 ml methylene chloride (DCM) and then with 150 ml acetone plus methanol (A+M). Samples from the second patient were divided (because of the large quantity of particles). Half was extracted in the same manner as with the first patient, and the other half extracted with an XAD-2 resin column. Each extract was filtered and concentrated to a final volume of 0.45 and 0.3 ml in dimethyl sulfoxide for the first and second patients, respectively.

Sampling Sites

Similar sampling sites were employed for both patients. The operating room air samples (OR) were taken at locations approximately 2.5 to 3 ft above the operative field. Control air samples (CR) were taken in a separate side room approximately 0.5 ft above the floor.

Mutagenicity Assay

All extracts were tested for the mutagenic activity in both standard tester strains TA98 and TA100 of *Salmonella typhimurium* using the *Salmonella* microsomal microsuspension test.[3] The system was motivated by adding increased numbers of bacterial cells (approximately 10^9) in a concentrated suspension to airborne particle extracts with or without S-9. The motivator, S-9, was prepared from the livers of male Fischer rats pretreated with Aroclor 1254 (500 mg/per kilogram of body weight). After 90 minutes of preincubation at 37°C, the mixture was processed according to the standard Ames test protocol.[4] The mutagenic activity was scored in tester cells from histidine dependence to histidine independence.

To test the stability of the smoke extract, an in situ assay, or "delay assay," was utilized. Samples were taken from the trapping media at intervals of 2, 4, and 6 hours after surgery for this in situ assay. These samples were plated on the appropriate agar plates to determine survival and mutation frequencies. Plates were scored after incubation at 37°C for 2 days.

The smoke extract was considered mutagenic if the number of histidine revertants (His Rev) was twofold or greater than the control and showed a dose-related response. Four dilutions or concentrations (undiluted, 1:2, 1:4, and 1:8) of the smoke samples were utilized to test this dose-related response.

A known mutagen (and carcinogen), 2-aminoanthracine, was used as a "positive control" for comparison. "Control room" air was tested as well as no addition to the strains, as a "negative control."

Results

The electrocautery smoke particles collected on the glass-fiber filters from both patients were found to be mutagenic to the TA98 strain of *Salmonella*. The TA98 strain did undergo alteration of its histidine dependence when exposed to the smoke extracts.

Smoke samples from the first patient (Table I) showed a positive response only with the S-9 activation. Samples from the second patient

TABLE I
Patient I: DCM Extraction

	Particles, µg/plate	Histidine Revertants for Each Strain			
		TA98		TA100	
		−S9	+S9	−S9	+S9
Negative control	—	7	5	44	46
Filter control	—	5	8	54	45
Air from control room	9	4	8	51	43
	18	7	9	60	47
	37	8	8	48	45
	73	8	11	53	48
Smoke from operating room	78	4	6	54	55
	155	6	8	64	52
	310	10	19	62	50
	620	10	31	62	55
Positive control*	2.5	1608			1926

*2-Aminoanthracine.

(Table II) showed a slight response even without S-9 activation. The mutagenic response of smoke samples from the organic solvent (DCM) extraction of the second patient was higher than that from the XAD-2 column extraction (Table II). No significant mutagenic response was found with the in situ assay. It appears that the smoke particles are unstable and lose their mutagenic potential within 2 hours.

The TA100 strain of *Salmonella typhimurium* did not appear to be significantly altered by the smoke.

Discussion

The findings of this preliminary study show that the smoke produced by the electrocautery knife during a reduction mammaplasty is mutagenic. The solvent extracts of the smoke changed the genetic makeup of the *Salmonella typhimurium*. The Ames test is a well-recognized and routinely utilized method of identifying compounds that are mutagenic.[4,5] Standard collection and analytical techniques were employed by NIOSH in evaluating the smoke. The results of the smoke retrieved from the operative field during our two reduction mammaplasties are convincingly positive.

The difference in the results of the two patients suggests that the mutagenic potential may vary among patients. The young patient in our study had dense, firm breast tissue that produced smoke in greater concentrations and with greater mutagenic response. Additional clinical study is needed to confirm this impression.

TABLE II
Patient II: DCM and XAD2 Extractions

	Particles, µg/plate	Histidine Revertants for Each Strain		
		TA98		TA100
		−S9	+S9	+S9
DCM extraction:				
Negative control	—	4	7	68
Filter control	—	3	6	64
Air from control room	17	4	8	52
	33	2	7	73
Smoke from operating room	265	5	37	54
	530	6	69	67
	1060	12	92	79
XAD2 extraction:				
Negative control	—	4	7	68
Filter control	—	4	7	59
Air from control room	17	2	8	55
	33	5	8	49
Smoke from operating room	265	4	24	57
	530	6	33	45
	1060	10	57	57
Positive control*	2.5		1551	1610

*2-Aminoanthracine.

We are obligated to discuss the significance of finding mutagens in the electrocautery smoke produced during surgery on our two patients. All smoke samples were found to contain mutagens, and the fact that only two patients were involved does not lessen the importance of these positive findings. Granted, concentrated smoke extracts were used in the testing. However, some significance must be granted to the mutagenicity potential found in the smoke samples.

Safe levels of ambient mutagens have not been determined and probably never will be. Variability among human subjects and the exposure times necessary to produce an ill effect will make it difficult to place accurate limits on exposure of known mutagens to people in an uncontrolled environment such as an operating room. Generally, the exposure time to smoke during a reduction mammaplasty is relatively short, and much of the visible smoke dissipates quickly as it rises from the operative field.

However, previous studies have demonstrated that all personnel in the operating room are exposed to a measurable amount of smoke when the electrocautery knife is used. The operating surgeon and the assistant surgeon have registered the greatest smoke exposure.[1]

Currently employed surgical masks are not designed to filter operating room air to render it suitable for safe aspiration. The small particle size of the smoke components may make it difficult to filter with a simple face mask. It may be possible to develop evacuation systems for the operative field to remove the smoke as it is generated.

Concern for overestimating health risks by extrapolation of experimental data has recently been raised.[6] It is easy to overreact when concern for safety in the workplace is at issue. We do not wish to take our findings and make assumptions about the actual health risk of electrocautery smoke exposure during a reduction mammaplasty. Our aim is not to further alarm surgeons who must already work in an environment that, at times, appears dangerous or hostile.

It is not known whether the smoke produced by the electrocautery knife during a reduction mammaplasty represents a serious health hazard. However, the smoke extracts collected in our operating rooms during surgery were able to alter the genetic makeup of the tester *Salmonella* bacteria. These findings cannot be ignored when evaluating the relative safety of electrocautery

smoke. The NIOSH report, filed after the smoke studies, made suggestions for health care workers who participate in operations where the electrocautery knife is utilized.[2] We concur with their conclusions and feel it is prudent to support the development of techniques to limit electrocautery smoke exposure in the operating room. Surgeons should be cognizant of this potential health risk and should attempt to limit their smoke exposure.

John E. Gatti, M.D.
South Jersey Medical Center
Suite 3
State Highway 70 at Eastgate
Cherry Hill, N.J. 08034

REFERENCES

1. Gatti, J. G., Murphy, J. B., and Noone, R. B. Analysis of electrocautery smoke produced during reduction mammaplasty. *Surg Forum* 37: 579, 1986.
2. Bryant, C. J., Gorman, R., Stewart, J., and Whong, W. *Health Hazard Evaluation Report, HETA 85-126-1932.* Cincinnati: NIOSH Publications, 1988.
3. Kado, N. Y., Langley, D., and Eisenstadt, E. A simple modification of the *Salmonella* liquid-incubative assay. *Mutat. Res.* 121: 25, 1983.
4. Ames, B. N., McCann, J., and Yamasaki, E. Methods for detecting carcinogens and mutagens with the *Salmonella*/mammalian-microsome mutagenicity test. *Mutat. Res.* 31: 347, 1975.
5. Whong, W. Z., Stewart, J., and Ong, T. Development of an in situ microbial mutagenicity test system for airborne workplace mutagens: Laboratory evaluation. *Mutat. Res.* 130: 45, 1984.
6. Bross, I. D. How to eradicate fraudulent statistical methods: Statisticians must do science. *Biometrics* 46: 1213, 1990.

Discussion

The Mutagenicity of Electrocautery Smoke

by John E. Gatti, M.D., Charles J. Bryant, C.I.H., R. Barrett Noone, M.D., and J. Brien Murphy, M.D.

Discussion by William R. Kanter, M.D.

This article by Dr. Gatti and colleagues on the mutagenicity of electrocautery smoke points to another of several potentially significant environmental hazards in the operating room for the surgeon and operating team. This study is one of the first to document the mutagenicity of smoke collected during an actual surgical procedure, in this case reduction mammaplasty. A previous study by Tomita et al.[1] also measured mutagenicity of smoke produced by electrocautery and by carbon dioxide laser under simulated surgical conditions. These authors also found significant mutagenic activity on TA98 and TA100 *Salmonella* strains, although the TA100 strains were less sensitive in their study than in the study presented here. In the study by Tomita et al., the mutagenic potential of smoke condensates from 1 gm of tissue was estimated to be equivalent to that from three to six cigarettes, with electrocautery smoke having twice the mutagenicity of laser smoke.

The National Institute of Occupational Safety and Health performed mutagenesis assays of operating room air samples, and, as described, mutagens were detectable by using the *Salmonella* tester strains TA98 and TA100 with organic solvent extraction of the material sampled from the air. However, in what is known as the in situ testing of these samples, no mutagenesis was found.[2] Several other assays were done on the air sample condensates from the operating room. Nitrosamines, among the most potent animal carcinogens, were absent from the samples, as were polynuclear aromatic compounds and aldehydes. Hydrocarbons were largely absent also, except for isopropanol, which is used as a sanitizing agent in the operating room. Particulates in the atmosphere ranged from 0.4 to 2.0 mg/m^3. The Occupational Safety and Health Administration has exposure criteria applicable only for biologically inert particulates referred to as "nuisance dust" of up to 10 to 15 mg/m^3, but no such criteria exist for particulate matter of biologically active material. Spectral analysis of the extracted particulate material shows much of it to be fatty esters.

It has been known that heating biologic tissues and proteins in particular to high temperatures results in molecules with higher aromatic ring structures and possibly unsaturated radicals. Some of these substances have been found to be mutagens, such as can occur in broiling or superheating of fish or beef.[3] It is therefore not surprising that electrocautery and lasers, which cause locally high temperatures in tissue, can produce potentially mutagenic substances. One interesting observation of Dr. Gatti and colleagues is that the smoke particles appear to be unstable, losing their mutagenic potential within 2 hours. This point should be kept in mind in interpreting any negative studies and their methodology.

The significance to the operating team is still to be determined. The exact nature and pharmacokinetics of such inhaled mutagenic material are undetermined, and there is no epidemiologic evidence that any harm has resulted to operating personnel or to patients from this effect. There is, however, a correlation between the bacterial mutagenicity level of airborne particles and lung cancer incidence in other settings.[4] Mutagens in the urine of operating room personnel have not been found to be elevated, as they have in heavy smokers.[5] Evidence of cytogenetic damage, as

Received for publication September 9, 1992.

shown by chromosomal aberration and sister chromatid exchange in lymphocyte culture, has been reported among operating room personnel, but the biologic significance of this, if any, is not known.[6] This reviewer could find no reference to an increased incidence of later malignancy in tissue treated by electrosurgery.

Although the significance of any detrimental effect of these mutagenic substances may not be agreed on, the generally offensive nature of the smoke is. Fortunately, several very simple systems have been devised that can be used to remove the smoke from electrocautery systems and can be fashioned from materials available to all of us in the operating room.[7,8] The simplest is to use Steri-Strips to strap suction tubing not far behind the Bovie tip to evacuate smoke or to assign the task of smoke evacuation to an assistant with a high-flow suction tip. More sophisticated smoke removal systems commercially developed for laser surgery are available and have various degrees of efficacy.[9] Surgical masks are generally not considered protective for the particle size found in electrocautery smoke (NIOSH, personal communication). As the authors point out, the National Institute of Occupational Safety and Health guidelines recommend using smoke evacuation units to minimize acute and chronic health effects that may result from exposure.

Until the risks to operating personnel are more clearly defined, it seems prudent to take at least simple measures to reduce the exposure to smoke from electrocautery.

William R. Kanter, M.D.
Physicians Pavilion at Owings Mills
10085 Red Run Boulevard
Suite 307
Owings Mills, Md. 21117

REFERENCES

1. Tomita, Y., Mihashi, S., Nagata, K., et al. Mutagenicity of smoke condensation induced by CO_2-laser irradiation and electrocauterization. *Mutat. Res.* 89: 145, 1981.
2. Bryant, C. J., Gorman, R., Stewart, J., and Whong, W. *Health Hazard Evaluation Report, HETA 85-126-1923.* Cincinnati: NIOSH Publications, 1988.
3. Nagao, M., Honda, M., Seino, Y., Yahagi, T., and Sugimura, T. Mutagenicities of smoke condensates and the charred surface of fish and meat. *Cancer Lett.* 2: 221, 1977.
4. Walker, R. D., Connor, T. H., MacDonald, E. J., et al. Correlation of mutagenic assessment of Houston air particulate extracts in relation to lung cancer mortality rates. *Environ. Res.* 28: 303, 1982.
5. Baden, J. M., Kelley, M., Cheung, A., and Mortelmans, K. Lack of mutagens in urines of operating room personnel. *Anesthesiology* 53: 195, 1980.
6. Natarajan, D., and Snathiya, S. T. Cytogenetic damage in operation theatre personnel. *Anesthesia* 45: 574, 1990.
7. Johnson, C. D., Sonenshein, H., and Brandes, W. Smokeless electrocautery tonsillectomy. *ENTechnology* 562, 1990.
8. Thorne, F. L. The useful smoke sucker. *Plast. Reconstr. Surg.* 77: 500, 1986.
9. The dangers of laser plume. *Health Devices* 19: 4, 1990.