Potential Ocular Damage from Microwave Exposure During Electrosurgery: Dosimetric Survey

Jacob D. Paz, PhD; Ralph Milliken, MD; William T. Ingram, MPH; Arthur Frank, MD, PhD; and Adam Atkin, PhD

A dosimetric survey of microwave radiation emitted by electrosurgical units used in operating rooms indicated that surgeons expose themselves to levels that may be hazardous, and that ocular exposures are especially high: 20 cm from the active lead, electric field strength at the eye/forehead position was 9.0×10^6 V^2/M^2 for the monopolar unit; and magnetic field strength at this position reached a magnitude of 3.5 A^2/M^2. These electric and magnetic fields exceeded the TLVs of the American National Standards Institute. The authors concluded that the high levels of microwave radiation generated by electrosurgery devices should receive immediate attention to assess health effects associated with such exposures.

We have performed an exploratory radiometric study of microwave (MW) emissions by electrosurgical units (ESUs) used in operating rooms. The study was undertaken to evaluate whether the MW exposure levels of the surgeons exceeded the new standards of the American National Standards Institute (ANSI),[1] in terms of both electric and magnetic field strengths.

Microwave (MW) and radiofrequency (RF) radiations are magnetic energies in the form of waves which travel at the speed of light. Radiofrequencies range from 100 kHz to 300 MHz, and microwaves, from 300 MHz to 300 GHz.[2] RF and MW radiation is classified as nonionizing because the energy of each photon is relatively low.

Only a few studies have been performed to assess RF/MW exposure levels of medical personnel. Until now, health hazards associated with electrosurgical units have been divided into four categories[3]: (1) explosion; (2) burns; (3) cardiac effects; and (4) muscle excitation. Exposure of medical professionals to RF/MW emissions from commonly used electrosurgical units has been neglected, though some data on emission levels have been published: Fox et al[4] and Paz and Milliken[5] have reported power densities of ESU emission exceeding 150 mW/cm^2; Ruggera and Segerson[6] found RF/MW electric fields of 1000 v/cm at 16 cm from an ESU source.

There is an extensive literature on bioeffects of microwaves. Although at least 130 categories of effects have been reported, the eye—especially its lens—seems particularly sensitive. Lens opacification sufficient to cause loss of visual function is generally referred to as "cataract." During the past 25 years, numerous investigations with animals as well as a few epidemiologic surveys of human populations have been devoted to assessing the relationship of MW exposures to subsequent development of ocular cataracts.[2,7–11] The severity of ocular damage induced by microwave radiation depends not only on its intensity, but also on its wavelength, and on the duration of exposure. The intensity data to be presented can, therefore, function only as a warning flag, signaling the immediate need for the other kinds of data, especially in view of what is known about the vulnerability of the eye.

Methods and Materials

Using Holaday Industry's RF/MW Monitor (Model No. HI-3002), electric and magnetic field strength

From the Department of Preventive Medicine, New York Medical College, Valhalla, NY (Dr Paz, Dr Ingram); the Department of Anesthesia, New York Medical College, Valhalla, NY (Dr Milliken); the Department of Preventive Medicine, University of Kentucky, Lexington, KY (Dr Frank); and the Department of Ophthalmology, Mount Sinai School of Medicine, New York (Dr Atkin).

Address correspondence to: 33 Riverside Dr, New York, NY 10023 (Dr Paz).

0096-1736/87/2907-0580$02.00/0

measurements were taken of a Riter Model 260 bipolar electrosurgical unit (used in neurologic surgery), and of a Bovie electrosurgical unit manufactured by Liebel-Flarsheim (commonly used in general and urologic surgery). The microwave monitor was calibrated and standardized prior to the survey and again at the end of the study by Holaday Industry, the manufacturer.

Results only of the near-field measurements are reported here. These were made as follows: The ESU and its leads were arranged as for use in the operative field, and an assistant was positioned to simulate the surgeon's bent-over position while operating, with eye-forehead region at a distance of 20 cm from the ESU's active lead, as observed for typical working postures. Measurements were then taken with the monitor probe positioned to correspond to each of the following body locations: eye/forehead; neck; chest; upper arms; lower arms; waist; and gonads. The assistant did not remain in the field while the measurement was being made. Several successive readings (usually three) of magnetic and electric field strength were taken at each position, and the value shown (Tables 1 to 3) is the highest of the replications.

Results

Electric field and magnetic field measurements for bipolar and Bovie electrosurgical units are shown in Tables 1 through 3.

With the bipolar ESU in the coagulation mode a peak electric field value of 9.0×10^6 V^2/M^2 was obtained at the eye/forehead position (Table 1). Electric field intensities taken at other upper body locations (neck, chest, and upper arms) with this unit ranged from 1.0×10^5 to 1.0×10^6 V^2/M^2. Electric field strength at the lower arm, waist, and gonad locations ranged from 1.0×10^4 to 5.0×10^4 V^2/M^2.

With the Bovie ESU, the exposure levels were somewhat lower at the eye/forehead position, reaching a magnitude of 1.0×10^5 V^2/M^2 (Table 2). Other body locations (neck, chest, arms, waist, and gonads) were exposed to levels of 1.0×10^4 to 5.0×10^4 V^2/M^2, measured in coagulation mode, and to levels of 1.0×10^3 to 2.0×10^4 V^2/M^2, measured in cutting mode. For both the bipolar and the Bovie ESU, electric field levels were generally lower in the cutting mode than in the coagulation mode (Tables 1 and 2), because the operating power is less in the cutting mode.

TABLE 1
Electric Field Strength Measurements E2 (V^2/M^2): Bipolar Electrosurgical Units

Body Organ	Coagulation Mode	Cutting Mode
Eye/forehead	9.0×10^6	2.0×10^4
Neck	1.0×10^6	3.0×10^4
Chest	1.0×10^5	3.0×10^4
Upper arms	1.0×10^5	5.0×10^4
Lower arms	5.0×10^4	4.0×10^4
Waist	1.0×10^4	4.0×10^4
Gonads	1.0×10^4	4.0×10^4

TABLE 2
Electric Field Strength Measurements E2 (V^2/M^2): Spark Gap Bovie Electrosurgical Units

Body Organ	Coagulation Mode	Cutting Mode
Eye/forehead	1.0×10^5	9.0×10^4
Neck	1.0×10^4	2.0×10^4
Chest	1.0×10^4	1.0×10^4
Upper arms	1.0×10^4	1.0×10^3
Lower arms	1.0×10^4	1.5×10^3
Waist	5.0×10^4	9.0×10^3
Gonads	5.0×10^4	1.0×10^3

TABLE 3
Magnetic Field Strength Measurements A2 (A^2/M^2): Bipolar Electrosurgical Units

Body Organ	Coagulation Mode	Cutting Mode
Eye/forehead	3.5	0.01
Neck	0.5	0.01
Chest	0.04	0.06
Upper arms	0.05	0.05
Lower arms	0.05	0.05
Waist	0.04	0.03
Gonads	0.01	0.02

With the bipolar unit operated in the coagulation mode, not only the electric but also the magnetic field strengths (Table 3) were high, reaching a value of 3.5 A^2/M^2 at the eye/forehead position. This exceeds the ANSI TLV.[1] Lower values of magnetic field strengths were noticed at the arms, waist, and gonads, ranging from 0.01 to 0.5 A^2/M^2. Again, field strengths were lower in the cutting mode.

For comparison purposes, Table 4 displays natural microwave background levels of E2 and H2, sampled at various spots in New York City.

Discussion

It appears that, due to the surgeon's position during electrosurgery, with eyes often at a short distance from the ESU (estimated to be about 20 cm from active lead), the most severely exposed areas are the eyes/forehead: The highest RF/MW electric field levels were measured in this region. Electric field levels at the locations of eye/forehead, neck/chest, and arms far exceeded the permissible level set by ANSI,[1] ie, by a factor of approximately 20 times for each exposure.

Natural urban background levels of RF/MW electric and magnetic fields, sampled at locations such as the New York subway, and near a microwave (radar) transmitter on Governors' Island (Table 4), were far below those obtained near the electrosurgical units (Tables 1 to 3). The latter exceeded the background measurements, by factors ranging from 10 to 1,000 times.

High levels of microwave emission from electrosurgical equipment have been reported at least three times before. Fox et al[4] measured the power flux densities along the active lead of electrosurgical units and found

TABLE 4
Natural Background Electric and Magnetic Strengths

Location	V^2/M^2	A^2/M^2
Subway platform	0.5×10^3	0.05
Oncoming train	5.0×10^3	0.15
Inside subway car	4.0×10^3	0.01
Governors Island	1.0×10^3	0.01
Near radar antenna	4.0×10^4	0.10
Ferry radar off	4.0×10^3	0.01
Ferry radar on	1.0×10^4	0.20

levels in excess of 150 mW/cm^2, with significant energy over the band from 100 MHz to 1 GHz (1000 MHz). They remark that "urologists doing trans-urethral resections are especially exposed since the radiating active lead enters the cystoscope near the eye."[4] Paz and Milliken[5] also found power densities with values exceeding 200 mW/cm^2 at a distance of 25 cm from an ESU's active lead; and Ruggera and Segerson[6] reported that electric field strengths were as high as 1000 V at 16 cm from an ESU source.

Although we cannot yet assess the hazard to health from these sources of RF/MW exposure, they raise some disturbing questions. There are a few reports of cataract development in humans after acute exposures. Zaret[12] has reported instances of cataract development which he attributed to microwave exposure at low levels (eg, values as low as 2 mW/cm^2), but his finding and conclusions have been challenged by Hathaway.[13] Thus, there are insufficient data to establish a threshold value for cataractogenesis in humans, and only extrapolation from animal studies[7-8,10-11,14] can be done. These showed that microwave cataractogenesis is a threshold effect: The rabbit eye required a minimum exposure level of 100 mW/cm^2.[7,10-11,14] Most of the studies in the past 15 years are consistent with safe human exposure below the permissible Occupational Safety and Health Administration standard of 10 mW/cm^2.[1,7,11]

The human epidemiologic studies of microwave effects on lenses are of limited validity. Estimates of cataract frequency have varied widely because of differences in population groups surveyed, and because we lack both standard definitions for grades of opacification and uniform methods for detection. Furthermore, careful control for age distributions is essential, because the most prominent characteristic of cataract development is its increase in incidence with age. A survey of cataract incidence in civilians ranging in age from 1 to 74 years, conducted by the National Center for Statistics,[15] found one or more cataract conditions in 9% of the population. For the various age groups less than 45 years, the frequency increased gradually from 0.4% at 1 to 5 years of age, to 4% in the 35 to 44 year age group. Then after 45 years of age frequency increased markedly, reaching a maximum in the oldest group examined: Of those 65 to 74 years of age, more than half had cataracts. Cataract data for personnel on active duty in the armed services (who are mainly healthy and relatively young males) showed the characteristic increase in cataract incidence with age, but no significant difference in incidence between an RH/MW-exposed group and the control group.[16-18]

However, a recent study by Hollows and Douglas[19] yielded interesting though still inconclusive clinical evidence: Radio linemen exposed to MW radiation from 558 kHz to 527 MHz, and to power densities ranging from 0.08 to 3956 mW/cm^2, had a suggestive increase in frequency of posterior subcapsular cataract, compared with their nonexposed control group.

In addition to radiation intensity, exposure duration plays a vital role in the development of eye injuries. As already mentioned, we have as yet no data on exposure histories of surgeons. However, we do know that during general abdominal surgery, the surgeon may use the ESU in coagulation mode 100 or more times in one operation. Furthermore, some surgeons operate many times per week, throughout the year, and continue thus for decades. Nevertheless, until we can accurately quantitate total exposure times, estimates of the potential for damage to the eye and to the lens must be based on rough guesses. At this point, we can only note the likelihood of frequent exposure to power densities considerably in excess of the standards based upon the estimated cataractogenic threshold in rabbits of 100 mW/cm^2.[7,10-11,14]

Another important factor to be considered is wavelength or frequency.[7,11] As with temporal exposure histories, we, at this point, have little information on spectral exposures: Our *intensity* data suggest the urgency of obtaining such information. The only relevant information in the literature on the energy frequency spectrum has been provided by Fox et al,[4] who reported that though ESU emissions extended up to 1 GHz, "maximum energy is concentrated below 100 MHz and peaks at 2.4 MHz in the spark gap electrosurgical units widely used in North America." This is important because it appears that the critical range of frequencies for cataract induction in animals extends from 0.8 to 10 GHz.[7,11] A recent review[20] concludes: "(a) Above 500 MHz, opacities of the eye may be produced when power densities exceed 150 mW/cm^2, if the duration of exposure is sufficiently long; (b) Although ocular injury has not been reported at frequencies below 500 MHz, its possibility cannot be excluded."

If we estimate that even 10% to 15% of the microwave energy in the operating room situation was in the spectral range required for cataractogenesis, then safe exposure levels may often be exceeded by surgeons, though the degree of health hazard is still highly uncertain. A relevant animal study has recently been reported,[21] and seemed to yield a reassuring result, in that no cataracts or other visible ocular abnormalities followed repeated exposure of monkey eyes to microwave power densities of 200 and 300 mW/cm^2. Although this does not give any support to our warning, neither does it weigh heavily against it, because the sample size was small. Implications to be drawn from the 300 mW/cm^2 result are weak because only six monkeys were involved. And the lack of positive result from the 200 mW/cm^2 exposure in a sample of 12 monkeys merely suggests an upper bound to the incidence of cataract induction: It can be inferred with better than 95% confidence that the cataractogenic incidence in monkeys so treated does not exceed 22%. But no convincing evidence is given against smaller effects: for example, if the actual cataractogenic incidence were 12%, there would be better than one chance in five of getting the reported null result with 12 monkeys, and if the incidence were 5%, the probability of the null result would be more than half. An increase in cataract incidence of 12% or even of 5% in exposed *humans* could not in good conscience be ignored.

Further, a new research report[22] points to an ocular danger of a different sort: Damage to corneal endothelium was detected in cynomolgus monkeys after 2.45 gigaherz irradiation for several hours at only 20 to 30 mW/cm^2 (continuous-wave) or even 10 to 15 mW/cm^2 (pulsed). This may be a cumulative nonthermal effect (possibly augmented by commonly prescribed topical medications).

In summary, though application of animal data to predict cataract induction or other eye damage in humans is complicated, due to anatomic and size differences,[11] our result strongly suggests that a potential for eye injury exists in the surgical specialties such as urology, in which electrosurgical units are frequently used. Further research is needed (1) to check the validity of the measurements obtained in an empty field, inasmuch as field strength in the near-field may be markedly influenced by the presence of a human body (R. F. Herrick, personal communication, 1984); (2) to obtain relevant data on specific absorption rates in the region of the eyes as a function of wavelength, and on the spectral distributions of ocular exposure; (3) to gather information on exposure levels and cumulated exposure times that occur in different surgical specialties; and (4) to determine actual risks, epidemiologically, from extended exposure histories.

References

1. American National Standard Safety Levels with respect to human exposure to radio frequency electromagnetic fields, 300 kHz to 300 GHz. *ANSI* 1982;95.1.
2. Silverman C: Epidemiological studies of microwave effects. *Proc IEEE* 1980;68:78–84.
3. Schellhammer PF: Electrosurgery: Principles, hazards, and precautions. *Urology* 1974;3:261–268.
4. Fox JWC, Knadle RT, Brook RH: Radiofrequency in the operating theatre. *The Lancet* 1976;1:962.
5. Paz JD, Milliken R: Radiofrequency degradation of anesthetic gases as a possible health hazard. *Read before American Chemical Society Annual Meeting*, Kansas City, Sept 1982.
6. Reis R: Potential interference with medical electronic devices. *Bull NY Acad Med* 1979;55:1216–1221.
7. Petersen RC: Bioeffects of microwaves: A review of current knowledge. *J Occup Med* 1983;25:103–111.
8. Birenbaum L, Kaplan LT, Metaly W, et al: Effect of microwave on the rabbit eye. *J Microwave Power* 1969;4:232–243.
9. Michaelson SM: Microwave biological overview. *Proc IEEE* 1980;68:40–49.
10. Carpenter RL, Van Ummersen CA: The effects of 2.45 GHz radiation. *J Microwave Power* 1968;3:3–19.
11. Cleary S: Microwave cataractogenesis. *Proc IEEE* 1980;68:49–55.
12. Zaret MM: Cataracts following use of microwave oven. *NY State J Med* 1974;74:2032–2048.
13. Hathaway JA: Letter to the editor. *J Occup Med* 1978;20:317–318.
14. Guy AW, Lin JC, Kramer PO, et al: The effects of 2450-MHz radiation on rabbit eye. *IEEE Trans Microwave Theory Tech* MTT-23 1975;6:492–498.
15. Silverman C: Epidemiologic approach to the study of microwave effects. *Bull NY Acad Med* 1979;55:1166–1181.
16. Cleary SF, Pasternak BS: Lenticular changes in microwave workers: A statistical study. *Arch Environ Health* 1966;12:23–29.
17. Odland LT: Observation on microwave hazards to USAF personnel. *J Occup Med* 1972;14:544–547.
18. Shacklett DE, Tredici TJ, Epstein DL: Evaluation of possible microwave-induced lens changes in the United States Air Force. *Aviat Space Environ Med* 1975;46:1403–1406.
19. Hollows FC, Douglas JB: Microwave cataract in radiolinemen and controls. *The Lancet* 1984;2:406–407.
20. Radiofrequency and microwaves. *Environ Health Criter* 1981;16:57.
21. McAfee RD, Ortiz-Lugo R, Bishop R, et al: Absence of deleterious effects of chronic microwave radiation on the eyes of Rhesus monkeys. *Ophthalmology* 1983;90:1243–1245.
22. McCally RL, Farrell RA, Bargeron CB, et al: Nonionizing radiation damage in the eye. *Johns Hopkins Apl Tech Dig* 1986;7:73–91.