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Health Hazards from Microwave Radiation

John T. McLaughlin, M.D.
Glendale, Calif.

INTENSE radiation of many frequencies of the electromagnetic spectrum will exert profound physiological effects. It is a question of relativity and degree when these become pathological effects and constitute a threat to the well-being and existence of the exposed individual. Some of the observed radiation effects are common to many frequencies of the spectrum, others are peculiar to a relatively small band.

Microwaves (radar) are usually considered to comprise that portion of the spectrum from 110 to 30,000 megacycles, pulsed or constant, with variable power. Each is generated in magnetrons or klystrons and obeys all the physical laws pertinent to radiant energy.

Heating of the body is the commonest physiological effect of microwaves. This has been adequately described in the literature and requires no repetition.[5, 13, 14, 17, 20-23, 11] All observed effects from heat conform to the rule that absorption is in inverse proportion to wave length and penetration is in direct proportion to wave length. Temperature increases in living tissues are dependent upon 4 factors: [13]

1. Specific area of the body exposed and the efficiency of the heat dissipating mechanism of this area.
2. Intensity of field strength of the radiation.
3. Duration of the exposure.
4. Specific frequency of the radiation.

A reported death due to hyperpyrexia from microwave exposure emphasizes the importance of this hazard.[17]

The purpose of this paper is to discuss the indirect thermal effects, the athermal effects and some possible theories of the biochemical change achieved with microwaves. A review of the extant literature and the clinical findings on a group of people exposed to microwaves are included.

Literature

Convulsions have been induced in rats exposed to microwaves of 12.25 cm.[2] The brain temperatures rose to 110 degrees F and there was no relationship with the prevailing body temperature. The convulsions followed this rapid and marked elevation of the brain temperature and were associated with minimal visible pathology in the brain tissue. Animals removed immediately upon the onset of the convulsions usually survived, but if not removed from the radiant field they died in 30 to 45 seconds.

Microwave radiation will cause a certain amount of bone absorption, and this is undesirable in the age group where bone growth occurs because the reaction is most marked at the epiphysis.[9] It is equally undesirable over healing fracture sites where new bone growth is desired.

The danger of x-rays from microwave equipment which is not completely and adequately sealed has been mentioned by Lidman and Cohn.[16] This is a real danger, not a theoretical one, and constant vigilance should be maintained to guard against it.

Temperature elevation increases molecular oscillations, and this is pertinent since microwaves are absorbed at the molecular level.[3] The increase in oscillations causes a shift of the spectral energy absorption pattern, increasing the efficiency of the longer wave lengths. This explains the extreme thermo-lability of proteins.

Dr. John T. McLaughlin obtained his M.D. in 1940 from Georgetown University, took a rotating internship at St. Mary's Hospital, Philadelphia, 1940-41, and attended the School of Aviation Medicine in 1943. He took postgraduate work in radiation physics at the University of Southern California in 1955. Dr. McLaughlin was an instructor of surgery at Jefferson Medical College, and assistant surgeon at Jefferson, St. Mary's and St. Joseph's hospitals, Philadelphia, for a number of years. He is now a Glendale surgeon and has published several medical papers.

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Any multicellular organism is a complex mass of dynamic protein. The more highly developed the animal, the more complex are protein dynamics. Each protein molecule is in a constant state of flux, with constant changes in its size, shape, molecular weight and electrical potential. The potential and polarity of the cell wall are constantly changing and thus affecting a change in the wall permeability and the transference of anions and cations across this membrane. Microwaves apparently induce a change in the ionic double layer at the cell wall.[26] Such a change affects the permeability of the membranes and consequently the physiology of the cell. The principal effect is change in intra- and extracellular cation concentration.

Anything altering this delicate balance will exert a profound effect on the cell and the organism. If the protein molecule so altered is concerned with reproduction, reproduction may be altered and the progeny, if any, may reflect the molecular changes. Of outstanding importance are molecular changes in intracellular enzymes. Each biochemical reaction is catalyzed by an enzyme. All enzymes are proteins, some simple and some complex; and enzymes, like all proteins are universally susceptible of thermal inactivation.

Microwaves are absorbed at the structural level and under proper circumstances may change the character of the protein molecule.[3] Absorption takes place as the rotational energy of the molecule is increased. Rotational quantae are functions of the principle moments of inertia, which are themselves functions of the molecular bond distances, the bond angles and the atomic masses. Increased oscillations of the intramolecular bonds lead to rupture of the bonds, completely changing the character and physical properties of the polymer.

In addition to absorption at the molecular level, Odeblad[18] has demonstrated proton absorption at 26.5 m.c.

Tissues may be photosensitized by any heterochromic source of light[10] and they will then react more violently to any radiation. In some instances this is a reversible reaction.

Cataracts resulting from microwave exposure are a result of the oxidation of the thiol group in the lens, changing a transparent to an opaque protein.[20] Oxidation of polypeptides leads to formation of toxic end products which are protoplasmic poisons.

Microwaves of 12.25 cm., in vitro, will alter the human serum protein pattern, increasing electrophoretic migration from 7.5 per cent to 36 per cent in direct proportion to molecular weight. There is a constant decrease, averaging 48.5 per cent in the amount of alpha 2 globulin and a constant increase averaging 105 per cent in the amount of gamma globulin. Noted was a relationship between exposure time and the serum changes. Synergism and antagonism between microwaves and x-rays were observed.

Microwaves of 12.25 cm., in vitro, will diminish the amount of heparin-like bodies in the blood and this effect is enhanced by x-rays.

Lefebvre[8] stimulated the growth of chick embryos by exposing them to microwaves, and he also carefully measured the elevation in temperature achieved. He could not duplicate this growth effect by elevating the temperature to a similar level with the usual modalities, nor could he duplicate it with ionizing radiation. He postulated molecular resonance as the underlying cause of the growth stimulation.

Short-wave irradiation will stress the pituitary-adrenal cortex system and stimulate the secretion of oxysteroids.[1] Increase of body temperature by any means will act in a similar manner, but this effect is not achieved by the application of external heat.

Short-wave irradiation of an isolated area of the rabbit causes depression of white cell formation,[12] while whole body radiation stimulates leucocytosis. Lidman and Cohn[16] examined the blood of 124 men who had been exposed to microwaves for periods from 2 to 36 months. They concluded there was no evidence of stimulation or depression of the erythropoieic or leucocytic systems of these men. Unexplained were the described cases of jaundice, although possible causes were suggested, and also the significant differences in reticulocytes between the controls and the exposed men. Selye[24] has shown that stress causes an increase in circulating reticulocytes and an increase in capillary fragility which is especially marked in the connective tissue of the liver, whether the insult or injury has been over the liver, or some other part of the body.

Barron[4] examined 226 subjects who had been exposed to microwaves for varying periods of time and found a significant decrease in polymorphonuclear cells in 25 per cent as compared to 12 per cent in the controls. There was also an unexplained elevation of the eosinophils and monocytes in the exposed man. Capillary fragility was disproportionately high in the control group, and this is unexplained. Further examination of 100 subjects after 6 to 9 months revealed a decrease in the red cells in excess of 10 per cent from the original in 42 per cent of the subjects. There was an increase in white cells in 58 per cent and an increase in polymorphonuclears in 35 per cent, but no significant change in the platelets.

Selye[24] has demonstrated that temperature elevations are initiators of stress reactions in the same manner as cold and will precipitate the usual alarm reaction and subsequent chain of events.

Acute microwave exposure of experimental animals will cause marked adrenal hyperemia with little change in the lipid distribution of the cells.[25] Chronic exposure leads to increased intracellular lipids. Rabbits exposed to diathermy suffer adrenal lipid depletion and adrenal necrosis. These correspond with the effects found from other stressors.

Stress leads to an increase in blood fibrinogen and fibrinolysin, and causes an increase in circulating reticulocytes.[25]

Adler and Magora have demonstrated the stress phenomenon resulting from short wave irradiation.[1] Such irradiation

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is the precursor of inflammation which causes increased capillary fragility.[7] This may be the result of an inflammatory substance, resembling oxygen, released by a proteolytic enzyme. Inflammatory reactions cause an augmentation of fibrin and consequent decrease in clot retraction. In the early stages of stress there is an increase in the amount of circulating steroids.[24] These increased steroids have an antifibroblastic effect and this is combined with reduction in protein and protoplasm to cause destruction of the muscular and elastic tissue in the walls of the small vessels. This leads to capillary fragility and tendency to bleeding, thrombasthenia.[27] Biggs suggested that fibrinolysis was a component of the initial alarm reaction of Selye. In the later alarm stages of stress there is adrenal atrophy and exhaustion, in which case any small stress will cause profound bleeding, shock and even death.

Microwaves may interfere with normal blood clotting and stimulate abnormal bleeding in the following ways:

1. They set up an inflammatory reaction leading to capillary fragility.
2. They set up a stress reaction and by interference with protein metabolism weaken the walls of the blood vessels.
3. They have an antifibroblastic effect, thus preventing healing of direct and indirect damage to vessel walls.
4. They destroy platelets.
5. They cause inflammation which increases the amount of fibrin and therefore interferes with clot reaction.
6. Fibrinolysis is an undesirable effect of the stress effect of microwaves.

Clinical Observations

In observing a large number of persons engaged in the manufacturing of microwave equipment who were exposed intermittently for various periods to microwave radiation, 115 were noted to exhibit various degrees of abnormal capillary fragility as manifested by the Rumpel-Leede test. The only cases examined were those who sought medical advice for the reasons outlined below. These represent only a small percentage of the total number exposed, and no effort could be made to determine what percentage of the exposed population might have been affected.

Field strength, frequency, and power factors are unavailable for security reasons. Exposure ranged from 1 to 3 hours daily at distances from 1 ft. to 50 ft. from the antennae. Each of the examined persons had experienced the sense of warmth that is a result of microwave exposure. Headache and a warm feeling when exposed are such common findings that they are accepted as a normal occupational hazard in this type of work. Unfortunately, many, in ignorance, allowed considerable heat to be generated in their bodies in order to achieve a therapeutic diathermy effect.

The Rumpel-Leede test was accomplished by maintaining the blood pressure cuff on the arm at a point midway between systole and diastole for 3 minutes and then counting the petechiae in a 4 cm. circle in the anticubital fossa. One plus equalled 10-19 spots, 2 plus 20-30 spots, 3 plus 31-40 and 4 plus more than 40 spots.

The number of cases seen defies the statistical occurrence of the idiopathic causes of purpura. There was no common exposure to the known causes of purpura such as organic arsenicals, gold salts, benzol, or sedormid. Thiurea and sulfonamides were eliminated. None of the patients were exposed to ionizing radiation; such a group constituted a different clinical picture. The only possible etiological factor common to all the cases was the exposure to microwaves. Three hundred controls were established in persons undergoing routine physical examinations. One case of purpura was found in this group, and he had been exposed to microwave radiation in his previous employment. The group comprised 64 women and 50 men, and one boy of 10 years.

Three cases of spontaneous purpura were the members of one family who live adjacent to an area where radar sets are tested. None had any other microwave exposure, and they were completely unaware of the cause of the purpura. Examination of the area showed them to be in the test pattern at a distance of at least 100 yards.

Purpura Related to Exposure Time

Rumpel-Leede	Average Time of Employment
One Plus	10.8 months
Two Plus	23 months
Three Plus	18 months
Four Plus	25.2 months

Complete blood count, color index, hematocrit, prothrombin, bleeding, coagulation, and clotting times were equivocal with no definite pattern discernible.

Sternal marrow studies showed occasional increase in the megakaryocytes, and nothing else.

Platelet counts were slightly depressed, averaging 154,000 in 13 patients.

Fibrin clot volume coincided fairly well with the platelet counts. One case of spontaneous purpura presented a pulseless patient in profound shock resembling adrenal apoplexy. After one year he was still disabled and had an abnormal electroencephalogram.

Representative Cases:

CASE I: White male—39, machinist, 2 years exposure. The patient struck the palm of his hand on a lathe chuck and in three days there was an area of ecchymosis 6 x 6 cm. at the site. In two more days, the ecchymosis extended from the finger tips to the elbow. Rumpel-Leede 4 plus.

RBC 5,220,000—WBC 16,500—Hb. 15.8 gm. Coagulation, bleeding and prothrombin times normal. Platelet count 176,000. Clot volume 19 per cent (normal less than 20 per cent). Repeat platelet count in 2 days 160,000. Clot volume 22 per cent. Sternal marrow showed an increase of immature megakaryocytes. The patient was treated with ab-

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solute bed rest, ice packs, and 1500 cc of whole blood, and recovered.

CASE II: White male—27, 1 year exposure, administration. December 4, 1952: The patient complained of tenderness and pain along the dermatome of the 12th left intercostal nerve. The past history was negative for any serious illnesses or blood dyscrasias. Physical examination was negative, except for paresthesia of this dermatome. Blood pressure 130/80. December 8, 1952: the paresthesia persisted, and there were many fine petechiae present in this dermatome. Rumpel-Leede was 4 plus, blood pressure 126/80. December 15, 1952: The patient was complaining of the paresthesia and generalized malaise. There were fine petechiae all over the body. Blood pressure 132/78. The spleen could be palpated. January 8, 1953: The patient complained of increasing malaise and his blood pressure was 90/60, and he was hospitalized.

Laboratory findings: The bone marrow smear appeared normal. Hematologic studies were within normal limits for the RBC, white count, differential, hemoglobin, hemoglobin, hematocrit, and sedamentation rate. The A.M. fasting eosinophile count was 167/c. mm and after ACTH, at 12:30 P.M. was 166/c. mm. Blood chemistry was within normal limits for serum chloride, total protein, albumin, globulin, fibrinogen, and NPN. Syphilis serology was negative. Testicular biospy showed normal tissue. Following were the sugar values in a glucose tolerance test. Fasting, 95 mg.; 30 minutes, 175 mg.; 1 hour, 230 mg.; 2 hours, 97 mg.; 3 hours, 100 mg.

A diagnosis of stress syndrome with temporary adrenal insufficiency was made and therapy instituted with cortisone .075 daily. The patient improved on this regimen and when the blood pressure stabilized at 130/80, the cortisone was reduced to 0.050 and then 0.025 daily. He was maintained on this dose until March 1, 1953 when he regained the 20 pounds he had lost, then all medication was discontinued. For 3 years he has maintained his weight and blood pressure and his only complaint is easy fatigability.

After 43 months, the stress of a tooth extraction precipitated a sharp fall in blood pressure and necessitated steroid fortification.

CASE III: White female, 26, exposure of 3 years, electronics assembly. One year before this incident the patient had undergone a tonsillectomy and because of persistent bleeding, suturing of the fossas and transfusions had to be resorted to. There was no history of any preceding bleeding dyscrasia.

February 18, 1953: patient bumped her left leg against a table and sustained a 2 x 4 cm. bruise of the pretibial area of the middle one third of the leg. The skin was unbroken and x-rays were negative for bone injury. The patient complained daily of increased soreness of the leg and by February 24, 1954, there was ecchymosis from the knee to the tips of the toes, and on this date the Rumpel-Leede was 4 plus. The patient entered the hospital and the laboratory findings were: WBC 6400; normal differential; RBC 3,800,000; Hb. 13.4; platelet count 152,000; hematocrit 39; bleeding, coagulation, prothrombin time, normal; serology negative; urine normal.

The patient was given 500 cc. of whole blood every day for a total of 1500 cc. at which time the bleeding stopped. The patient was at absolute bed rest with the limb elevated and with ice applied.

On March 1, 1953, a large hematoma was evacuated from the injury site and the wound healed well. There was a residual hemarthrosis of the ankle and brawny discoloration of the skin of the limb. With physiotherapy there was a return to normal motion in the ankle and complete loss of edema in six months.

The discoloration of the limb remains unchanged.

CASE IV: White female—28; 6 months exposure; assembler. This patient was first seen May 15, 1953, when she was complaining of malaise and red spots on arms. Spontaneous petechiae were present all over the body with a 4 plus Rumpel-Leede. There was no history of previous bleeding dyscrasia or purpura. Past history was not remarkable for easy bleeding. On May 25, 1953, she fell while dancing and was reported to have hit her head but was not unconscious. She was seen again in May 26, 1953, complaining of pain in the right shoulder and the petechiae were still present.

On May 28, 1953, she fainted at work and when seen she was unconscious. BP 120/90 and neurological examination disclosed nuchal rigidity and a positive left Babinski reflex. The patient was removed to the hospital where spinal fluid was grossly bloody and at pressure of 300 mm. of water. A tentative diagnosis of subarachnoid hemorrhage was made. All blood studies were normal except fibrin-clot volume which was 27 per cent. Absolute bed rest was instituted, and in one week the patient had improved and skull x-rays were negative for pathology. Bilateral cerebral angiograms done at this time failed to reveal any aneurysm. Continuous bed rest was enforced and the patient went home by ambulance June 10, 1953. She continued in bed at home and was asymptomatic until June 24, 1953, when she arose to go to the bath and fell dead on the floor.

At autopsy, no aneurysm was found. There was evidence of a recent hemorrhage into the right lateral ventricle and an xanthochromic area in the same cavity indicated the site of previous bleeding. There were small petechiae throughout both hemispheres of the cerebrum. In addition there were infarcts of the spleen and myocardium and subserosal bleeding in the spleen and in some areas in the small bowel. There was engorgement of the liver without infarction. The postmortem findings in the spleen, liver, myocardium and small bowel bore a close resemblance to the changes

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following experimental exposure in animals described by Boysen.[5]

Later in the series 15 patients were treated with BAL (2,3 dimercaptopropanol), 2.5 mg. per kilo being given twice daily for three days. Each of these patients demonstrated a 4 plus Rumpel-Leede, and they presented themselves with the following complaints:

Intercostal neuritis	3
Ecchymosis of hands and fingers after wringing a mop	1
Joint pains	3
Tenosynovitis	4
Spontaneous ecchymosis	2
Mild contusion and severe hematoma	1
Spontaneous purpura	1

In each instance there was a complete remission of the presenting symptom or sign after three days of treatment.

The 2 thio groups of the BAL are highly reactive and apparently afforded protection to the more stable protein molecule.

Discussion

Microwaves are a potential health hazard and will continue as such until adequate studies point to the amount of such energy the human may safely absorb.

In addition to amounts of energy, this safety standard must consider frequency which, in this range of the spectrum, is an important factor. Penetration and absorption of microwaves are both functions of frequency, hence power is not the only element of danger to be considered. The amount of energy to which one is exposed is important, but we must speak in terms of the amount of energy being absorbed and at what depth in the body absorption occurs. The answers to these and other important questions can only be arrived at by giving due consideration to frequency.

A standard of how much energy one may safely absorb per square centimeter will be inadequate unless we can state the total amount of energy he may absorb and in what period of time. Currently we have no information whether there may be a cumulative effect from exposure to microwaves, but Selye's work on stress points out the pathological differences resulting from acute and chronic exposure to short-wave radiation.

Since some of the undesirable effects of microwave exposure are from the heat created, there will be different safety levels for different organs, since the capacity for cooling varies in different parts of the body; muscle and bone can obviously be heated with a greater margin of safety than the brain or the lens of the eye.

Currently we have no unit of nonionizing radiation which we may use as a standard, hence communication is complicated.

Today the average human is exposed to a multiplicity of frequencies of the electromagnetic spectrum which were undreamed of 2 decades ago. Infrared and ultraviolet modalities are common accessories in the average home, school, and place of business. Ionizing radiation has emerged from its protective shell and Geiger counters are now toys for children. There is a proved synergism and antagonism between various forms of radiation, therefore, any safety program must consider the interaction of the various forms of energy and prepare to cope with this extraneous factor.

Microwaves are part of our way of life, and exposure is not limited to military personnel, nor persons engaged in the fabrication of this equipment. It would behoove us to establish a definite clinical and pathological pattern of exposure and make this information and knowledge available to every physician, since they are the ones who will examine and treat the majority of the affected patients. Simultaneously, a satisfactory method of treatment would be a valuable addition to the physician's armamentarium.

Summary

Microwaves affect man adversly in at least 4 ways:

1. They may raise tissue temperatures to intolerable levels and cause cellular damage or death.
2. Emanation of x-rays, as mentioned by Lidman and Cohn, is a real danger and one to be guarded against.
3. Molecular absorption of microwaves may interfere with cellular physiology in an infinite number of ways.
4. Microwaves, directly as heat, or in some other manner, act as stressors and set off the stress reaction with all its undesirable sequelae which follow in the wake of the acute alarm reaction.

One clinical pattern of capillary fragility, failure of adequate clot retraction, and abnormal bleeding, has been presented.

Experimental work to date has merely demonstrated the danger from exposure to microwaves of 12.25 cm. Until further information is available, this form of energy should be afforded the same respect as other energetic radiations such as x-rays, gamma rays, and neutrons.[13]

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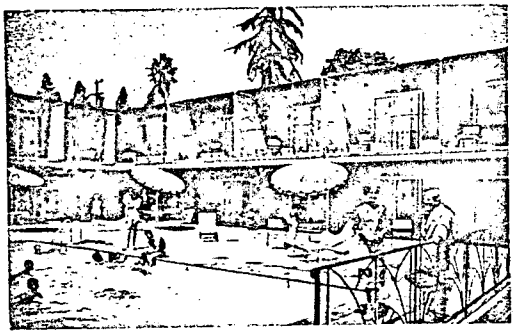

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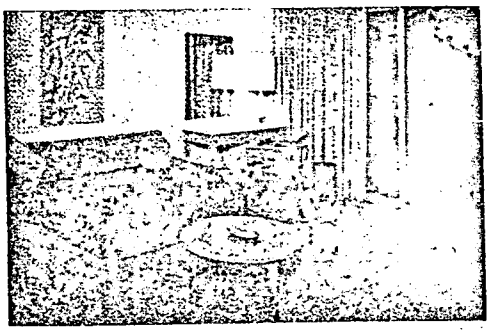

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