Leukocyte Response following Simultaneous Ionizing and Microwave (Radar) Irradiation

By R. A. E. Thomson, S. M. Michaelson and J. W. Howland

With the increased use of microwave generating systems, some with maximum output in excess of 1 megawatt, information on the biologic effect of microwaves is of importance.

Microwave energies range in the radio-frequency region of the electromagnetic spectrum from 300 megacycles/sec. (Mc./sec.) up to 300,000 Mc./sec. This is equivalent to a wave length range of 100 cm. down to 0.1 cm. Microwave radiation is produced by electron tubes such as klystrons, magnetrons and thyratron tubes, which are capable of peak plate voltages in excess of 200 kilovolts. As a result, hard x-rays, (up to 250 KVP) can be produced during their operation. When functioning, such tubes are shielded to reduce incident x-radiation to tolerance limits. In general, electromagnetic radiation of shorter wavelengths than visible light produces a photoelectric or an ionization effect, and those of longer wavelengths (infrared to radio-frequency region) produce a thermal effect.

A potential occupational hazard among radar workers is simultaneous exposure to x-radiation and microwaves. Leukocyte changes produced by x-irradiation in many animal species have been well described. Leukocyte changes following microwave exposure are primarily described in rodents. During studies on the biologic effect of microwaves it was observed that x-irradiated and simultaneous microwave and x-irradiated dogs exhibited characteristic differences in leukocyte response.

Material and Methods

Adult mongrel dogs of either sex, 1 to 5 years of age, were used. Each animal was exposed in a Plexiglas cage, 23 inches long, 12 inches wide and 24 inches high, placed in an anechoic chamber, 7 feet high, 7 feet wide and 15 feet in length.

The microwave source was an AN/MPS-14 radar set operated at 2800 Mc./sec. Pulse rate frequency was 360 per second, pulse width 2 microseconds, and field intensity 100 mW/cm.² (±20 per cent).

From the Department of Radiation Biology and Biophysics, University of Rochester School of Medicine and Dentistry, Rochester, New York.


This certifies that the experiments described in this paper were conducted according to the "Rules Regarding Animal Care" as established by the American Medical Association.

First submitted Sept. 17, 1965; accepted for publication Nov. 13, 1965.

Roderick A. E. Thomson, M.T., M.R.S.H.: Technical Associate, Department of Radiation Biology and Biophysics, University of Rochester School of Medicine and Dentistry. Sol M. Michaelson, D.V.M.: Associate Professor, Department of Radiation Biology and Biophysics, University of Rochester School of Medicine and Dentistry. Joe W. Howland, M.D., Ph.D.: Professor, Department of Radiation Biology and Biophysics, University of Rochester School of Medicine and Dentistry.
Table 1.—Dog Response to Microwave Exposure of 360 Min. Duration (2800 Mcycles sec., 100 mW cm.² Field Intensity)

<table>
<thead>
<tr>
<th>No. of Dogs</th>
<th>Determination</th>
<th>WBC $\times 10^3$</th>
<th>Neutrophiles $\times 10^3$</th>
<th>Lymphocytes $\times 10^3$</th>
<th>Hematocrit</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Pre-exposure</td>
<td>13.54 ± 0.82</td>
<td>9.23 ± 0.87</td>
<td>3.43 ± 0.48</td>
<td>48.0 ± 2.0</td>
</tr>
<tr>
<td>9</td>
<td>Post-exposure</td>
<td>15.77 ± 1.36</td>
<td>11.95 ± 1.59</td>
<td>1.38 ± 0.25</td>
<td>49.5 ± 3.0</td>
</tr>
<tr>
<td>8</td>
<td>1 day</td>
<td>16.63 ± 2.14</td>
<td>12.14 ± 1.81</td>
<td>3.24 ± 0.68</td>
<td>48.0 ± 3.0</td>
</tr>
<tr>
<td>8</td>
<td>7 days</td>
<td>11.56 ± 0.86</td>
<td>7.48 ± 0.55</td>
<td>3.17 ± 0.51</td>
<td>46.0 ± 1.5</td>
</tr>
<tr>
<td>9</td>
<td>14 days</td>
<td>9.46 ± 1.01</td>
<td>5.84 ± 0.43</td>
<td>2.89 ± 0.63</td>
<td>46.6 ± 1.5</td>
</tr>
<tr>
<td>9</td>
<td>28 days</td>
<td>9.12 ± 0.70</td>
<td>6.03 ± 0.38</td>
<td>2.35 ± 0.43</td>
<td>48.4 ± 2.1</td>
</tr>
</tbody>
</table>

Mean ± standard error of the mean.

X-radiation was from an Andrex industrial x-ray unit operated at 250 KVP. 4 ma. half value layer 0.65 mm. Cu. The dose rate measured in air with a Victoreen R meter was 2 R/minute.

The central microwave and x-ray beams were directed horizontally along the midline plane of the cage and intersected at a ninety degree angle. The animal was free to move within the cage, and was observed throughout the radiation period of 6 hours. Ambient temperature of the chamber was maintained at 72 F. by an air conditioner unit.

Leukocyte count and hematocrit determinations were performed on blood samples obtained by jugular venipuncture immediately before and after irradiation, as well as during recovery at intervals up to 60 days following exposure.Rectal temperature and body weight changes were noted.

**Results**

The hematologic response of dogs to 2800 Mc/sec. exposure of 360 minutes duration at 100 mW/cm.² is presented in Table 1.

Immediately following simultaneous microwave and x-irradiation, leukocytes increased from a pre-exposure level of 8.1 ± 0.81 to 17.6 ± 4.9 thousand cells per cu. mm. (217 per cent). After x-irradiation alone, leukocyte changes ranged from 10.5 ± 0.91 to 9.6 ± 0.68 thousand cells per cu. mm. (Fig. 1). A progressive leukopenia then occurred in both groups. This was maximal, at 50 per cent of the pre-exposure value, at the 7-day post-irradiation period. Leukocyte values returned to the pre-exposure level by the fourteenth day after combined exposure. Recovery to the pre-exposure level after x-irradiation alone was delayed to the fifty-first day.

Neutrophils increased from a pre-exposure level of 4.38 ± 0.54 to 15.76 ± 4.66 thousand cells per cu. mm. (360 per cent), following simultaneous irradiation (Fig. 2). The general neutrophil response in both groups was similar in pattern to their leukocyte count change. Variation in weekly neutrophil count, which appeared to follow a 14-day cycle, following combined exposure, progressively diminished.

Lymphocytes decreased to 60 per cent of a pre-exposure value of 2.50 ± 0.26 thousand cells per cu. mm. immediately following combined irradiation (Fig. 3). From x-irradiation alone the decrease was 25 per cent below the initial value of 2.7 ± 0.6 thousand cells per cu. mm. One day following exposure, lymphocytopenia was maximum in both groups of animals, with levels 50 to 60 per cent below pre-exposure values. Fifty-eight days after...
LEUKOCYTE RESPONSE FOLLOWING IRRADIATION

Fig. 1.—Leukocyte recovery after microwave and x-irradiation (6-hour exposure).

Fig. 2.—Neutrophile recovery after microwave and x-irradiation (6-hour exposure).

x-irradiation, lymphocyte recovery to the pre-exposure level was observed. Lymphocytes were slightly more diminished after the combined irradiation, and at 60 days continued to be below the pre-exposure level.

Hematocrit decreased one day after exposure (Fig. 4). Recovery to the pre-exposure level became apparent by 44 days in animals given x-irradiation alone. Combined irradiated animals showed a sustained decrease in hematocrit from the first to the sixtieth day following exposure.

Data on microwave and sham-exposed dogs are included in Table 2 for comparative purposes. X-irradiation during microwave exposure caused no significant change in rectal temperature increase or in the body weight loss
which follows microwave exposure. X-irradiated dogs showed a decrease in rectal temperature comparable to that observed in the sham-exposed dogs, but less loss in body weight.

The animals exhibited no unusual response during x-ray or simultaneous microwave and x-ray treatment. By 3 months post-exposure there was a typical greying of the coat. Mortality did not result from the exposures.

**DISCUSSION**

Microwaves can be reflected, refracted, scattered, absorbed or completely nonabsorptive, depending on the size and composition of the biologic material interposed in its path. When tissues are exposed to microwaves, the radiant energy absorbed is transformed into increased kinetic energy of the absorbing molecules, thereby producing a general heating of the entire medium. This in biologic systems is modified by mechanisms of heat loss primarily neurocirculatory in type. Tolerance of animals to microwave exposure is very dependent on the microwave field intensity and specifically on the total amount of energy absorbed. When the thermoregulatory capability of the animal is exceeded, death can result.\(^1\) Six-hour, 2800 Mc./sec., 100 mW/cm.\(^2\) exposures used in this
study are easily tolerated by normal dogs. To permit survival from x-irradiation after a 6-hour period of simultaneous microwave and x-irradiation, a low x-ray dose rate, 2R/min., was used. The total x-ray dose of 720 R at 2R/min. is shown to be a sublethal dose. As x-ray dose rate is protracted, the total dose capable of a lethal or specific damaging effect is increased.2

Leukocyte changes, including neutrophilia and lymphocytopenia, which result from microwave exposure suggest a stress effect.1 The differing hematologic responses between the x-irradiated and simultaneous microwave and x-irradiated animals suggest that microwave treatment alters the response to x-irradiation. It is doubtful that the microwaves alone caused the leukocytosis noted immediately after combined irradiation as such marked leukocytosis never was observed in similarly microwave exposed dogs (Table 1). The best explanation for this phenomenon is that of a combined irradiation stress effect. The more marked depletion of lymphocytes during the first week after the combined microwave and x-irradiation exposure also indicates a certain additivity of effect over that which occurs when only x-irradiation was administered. Since an earlier and more sustained neutrophil recovery resulted after the combined irradiation, the x-irradiation effect on neutrophils would appear to be modified by the microwave energy. The cyclic neutrophil recovery pattern as shown in Figure 2, characterized by gradual diminishing peak counts at 14-day intervals, may represent a stimulated neutrophil production, thereby cancelling the neutrophil loss which results from the x-irradiation. As time after termination of exposure increases, the x-irradiation effect diminishes, and the stimuli directed toward neutrophil production are reduced. For such a response to occur, a bone marrow change would be suggested. Erythropoietic recovery, as indicated by hematocrit changes, exhibits a more deleterious effect on erythrocytes from the combined irradiation exposure than from x-irradiation alone (Fig. 4). In rats it has been found that microwave exposure has a definite effect on hematopoietic organs. The extent as well as specific latency of these changes depend on the specific intensity and duration of exposure.3

Microwave effects which include hypoxia, (mentioned by Hartman4), molecular alteration (Bach5), thermogenesis and stress1 may be capable of modifying sensitivity to the ionizing effects of x-irradiation. Hypoxia may reduce the formation or toxic effect of free radicals; molecular alteration may modify the

---

**Table 2.—Rectal Temperature and Body Weight Changes after Exposures of 360 Min. Duration**

<table>
<thead>
<tr>
<th>No. of Dogs</th>
<th>Treatment</th>
<th>Rectal Temperature (°F)</th>
<th>Body Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>Change</td>
</tr>
<tr>
<td>8</td>
<td>X-ray†</td>
<td>101.8 ± 0.2*</td>
<td>-1.4 ± 0.3</td>
</tr>
<tr>
<td>5</td>
<td>Microwave and X-ray†</td>
<td>101.8 ± 0.2</td>
<td>+1.1 ± 0.3</td>
</tr>
<tr>
<td>9</td>
<td>Microwave</td>
<td>102.0 ± 0.3</td>
<td>+1.8 ± 0.8</td>
</tr>
<tr>
<td>27</td>
<td>Sham</td>
<td>101.8 ± 0.01</td>
<td>-1.3 ± 0.2</td>
</tr>
</tbody>
</table>

*Mean ± standard error of the mean.
†250 KVP, 2 R/min. MAD-720 R total dose.
12800 Mcycles/sec., 100 mW/cm² field intensity.
target molecules and affect molecular changes. Thermogenesis and stress effect may influence metabolism and endocrine responses. More severe injurious effects of x-irradiation at lethal x-ray dose levels, with the complex reactions which result in death, may exceed or nullify the modifying capabilities of microwaves to the extent that similar changes as noted in the combined microwave and x-ray exposure at a sublethal x-ray dose level would not result. Hematologic assessment of x-radiation injury in which combined microwave and x-irradiation exposure is involved should include consideration of possible alteration in hematologic response from microwaves. The need for additional studies of the effect of microwaves on leukopoiesis and erythropoiesis is apparent from the observations presented.

**Summary**

Simultaneous microwave and x-irradiation at a sublethal x-ray dose level modify the hematologic response to x-irradiation. Earlier neutrophil recovery and delayed lymphocyte and hematocrit recovery resulted following simultaneous microwave and x-ray exposure.

**Summario in Interlingua**

Le simultanea irradiation microundic e roentgenologic a un dosage sub-lethal de radios modifica le responsa hematologic al roentgeno-irradiation. Un plus prompte restablimento neutrophilic e un retarde restablimento lymphocytic e del hematocrite resultava ab le exposition simultanea a microundas e radios X.

**REFERENCES**

Leukocyte Response following Simultaneous Ionizing and Microwave (Radar) Irradiation

R. A. E. THOMSON, S. M. MICHAELSON and J. W. HOWLAND

Updated information and services can be found at:
http://www.bloodjournal.org/content/28/2/157.full.html
Articles on similar topics can be found in the following Blood collections

Information about reproducing this article in parts or in its entirety may be found online at:
http://www.bloodjournal.org/site/misc/rights.xhtml#repub_requests

Information about ordering reprints may be found online at:
http://www.bloodjournal.org/site/misc/rights.xhtml#reprints

Information about subscriptions and ASH membership may be found online at:
http://www.bloodjournal.org/site/subscriptions/index.xhtml