Glaser ✓

Proc. 2nd Internat Conf. on Med. Electronics 401-407 (1960)

ULTRASONIC EFFECTS COMPARED WITH BIOLOGICAL MICROWAVE EFFECTS

Victor T. Tomberg, Ph.D.

Director of Research,* Biophysical Research Laboratory, New York

SUMMARY: Three classes of microwave effects are reviewed. These are: ordinary thermal effects; specific thermal effects; and electric, non-thermal effects, when energies below 1 W/cm² are used, as in therapeutic treatments, or above 1 W/cm², as in chemical and industrial applications, where destructive or strong heating effects are desirable. Ultrasonic effects are known to be (1) thermal effects; (2) mechanical vibration effects often associated with cavitation phenomena; (3) chemical effects, i.e., forming free radicals, luminescent phenomena, etc. Using pressure sensitive probes and sensitized thermocouples, we found two energy ranges responsible for thermal and non-thermal effects. We found a high similarity between the physical effects in the ultrasonic and microwave fields, which could be useful in research and practical applications as well as in preventing health hazards.

SOMMAIRE: Les trois catégories d'effets des micro-ondes sont passées en revue. Ce sont: les effets thermiques ordinaires; les effets thermiques spécifiques, et les effets électriques non thermiques, produits soit par l'utilisation d'énergies inférieures à 1 watt/cm² comme par exemple en thérapeutique, soit au-dessus de 1 watt/cm² pour les applications chimiques et industrielles où l'on recherche des effets destructifs ou de hautes températures. Les effets ultra-soniques sont classés comme suit: (1) effets thermiques; (2) effets de vibration mécanique souvent associés à des phénomènes de cavitation, et (3) effets chimiques, c'est-à-dire donnant des radicaux libres, des phénomènes de luminescence etc. L'utilisation de sondes de pression et de thermocouples sensibles, a permis de mettre en évidence deux gammes d'énergie responsables des effets thermiques et non thermiques. Il existe une grand similitude dans les divers types d'effets physiques dans le domaine des ultra-sons et des micro-ondes, pouvant être d'une grande utilité dans la recherche et dans les applications pratiques, ainsi que dans la prévention des maladies.

MICROWAVES (MW) and ultrasounds (US) were introduced as means of medical treatment and biological research in 1926 and 1938 respectively.[1–5] It was then recognized that either harmful or stimulating and beneficial effects were produced, depending, as in other kinds of irradiation, on the applied dose. In general, weak doses produce beneficial and stimulating effects, and strong doses produce destructive effects. However, even destructive effects can be used beneficially under certain conditions and for certain applications, as, for instance, in surgery.[6, 7] The applied energy in MW, or short-wave diathermy, is less than 1 W/cm², using the

* Formerly associated with the Faculté de Médecine, Université de Bruxelles.

bipolar method of a condenser field with a frequency in the 3–30 m wavelength range. The applied energy in the US treatment with a stationary transducer is 0·2–0·6 W/cm^2 at frequencies between 800 kc/s and 3,000 kc/s. Using the US treatment with a moving transducer, the intensity may be several times greater to be effective without being harmful. Any energy levels higher than the above-mentioned values may be considered as harmful, and the physio-therapeutical energy range was and is strictly limited to the lower energy range.

Because the two energy ranges overlap, according to the tolerance and other biologically differing factors of a body, a great deal of research has been carried out to find out what exactly is the mechanism of MW and US fields and what are their safety limits.

In reviewing this kind of research, which is being carried out by hundreds of other investigators as well as ourselves, we find that there is a similarity between MW and US effects in which we are very interested today, because of some technical developments concerning the applications and the increased hazards of irradiation. The frequency range for MW applications, i.e. radar, is, moreover, much higher today than the range used in physiotherapy, which means that we should be concerned more with the energy range of destructive effects than with that of beneficial ones.

In order to explain the physical and biological effects and actions, I should like to repeat some generalities.

MW fields are applied therapeutically by placing the body or the object to be treated in a condenser field, or in a cylinder or flat coil field, or in an antenna, dipole or cavity field consisting of a radiating h.f. field.

US fields are applied by bringing the vibrating transducer area in contact with the body through a liquid agent. When an object is irradiated, a biological effect is possible only when the object absorbs energy. The quality and quantity of the effect depends largely, therefore, on the object itself, since it distorts the field and concentrates the lines of force in a regular or irregular form on itself. How regular or irregular this concentration will be, depends on the homogeneity and structure of the object, as well as on its electrical (MW) or mechanical (US) factors. The electrical factors are principally the electrical conductivity, the dielectric constant and the dipole moment. The mechanical factors are: the propagation constant of the sound through an object, and the absorption constant.

Biological objects have one thing in common: (1) they are heterogeneous and composed of particles or layers which have different electrical or mechanical constants, and (2) their thermal conductivity is very poor; this factor plays an important part in producing specific thermal effects.[8–14]

Therefore, a heterogeneous object absorbs the field energy irregularly. Hence, the energy levels may reach dangerous proportions in some parts of a heterogeneous object, even in fields whose overall intensity is weak and in the low dose range.[11, 12]

What happens to the absorbed electrical (MW) and mechanical (US) energy? As we know, this energy is primarily converted into heat, and this is known as the Joule Effect. Besides this thermal effect, other energy conversions are possible, i.e., mechanical (oscillating) and chemical ones, which we call non-thermal effects. In order to find out if a certain reaction is caused by a thermal or non-thermal effect, we prefer to rely on thermal control tests. We heat a control sample by ordinary caloric methods, i.e. in a water-bath, and we note whether we obtain the same effect as by means of irradiation, or whether we can imitate it only approximately or not at all.

As was found in the early beginnings of MW and US research, numerous effects have been observed which could not be imitated in the water-bath, and have therefore been called " electrical effects of non-thermal nature ", or athermic effects. Other authors as well as ourselves could, nevertheless, show that those effects are of a thermal nature and biologically the most dangerous ones, being very difficult or impossible to measure and to check. We called those effects " specific thermal effects."[10-12, 15-18] They are irregularly distributed and locally caused by high temperature peaks or gradients in heterogeneous objects of very poor thermal conductivity. In this case, parts or particles of an object become heated more quickly than heat equalization, by cooling from outside or by inside conductivity, is able to overcome, and therefore there are produced locally overheated particles or discrete areas of specific nature, which cannot be obtained by conventional heating methods, such as those of control testing. The temperature produced in these discrete areas or particles is much higher than the average temperature increase of the irradiated object.

Given a homogeneous field of high frequency, in which are placed solid or liquid particles having an electric conductivity k and a dielectric constant ϵ, the maximum heat will be produced[1, 2, 19] where the frequency $f = 2k/\epsilon$. Inhomogeneities of the field and interboundary discontinuities of the object change the produced temperature differences and gradients. We showed, for example, that wetting agents change significantly the pattern of the temperature distribution within a heterogeneous object. Others have shown that the introduction of gas bubbles changes the selective or specific-thermal action.

Similarly, in US fields these specific-thermal effects are the most important ones. Fig. 1 shows diagrammatically how the US energy is converted into mechanical, chemical and luminescent effects. The mechanical vibration

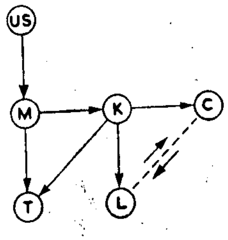

Fig. 1. Diagram showing the relationship between the different US effects. The US field produces mechanical effects M *through pressure and dilatation gradients. This mechanical action is converted into heat and specific-thermal effects* T *directly, or first into cavitation* K *and then into thermal effects. Cavitation produces chemical effects* C *and luminescent effects* L. *It is possible that chemical effects produce luminescent effects also, and vice versa*

is directly converted into heat. After a certain threshold, the gaseous cavitation phenomenon occurs; it consists in periodically building up and collapsing air bubbles, such as are present in most biological objects.[4] This cavitation produces (1) mechanical destructive effects, i.e. depolymerization; (2) locally concentrated temperature effects, i.e. specific-thermal effects (T) and (3) chemical effects (formation of H and OH radicals), as well as luminescent phenomena.[13, 14] It is not yet known if these luminescent phenomena produce chemical effects or are themselves produced by the cavitation-induced chemical action.

Fig. 2 illustrates the biological effect of the different energy conversions. The increase in the metabolic effect $M\%$ is given in dependence on the temperature T in °C, the cavitation effect K and the chemical effect C. We

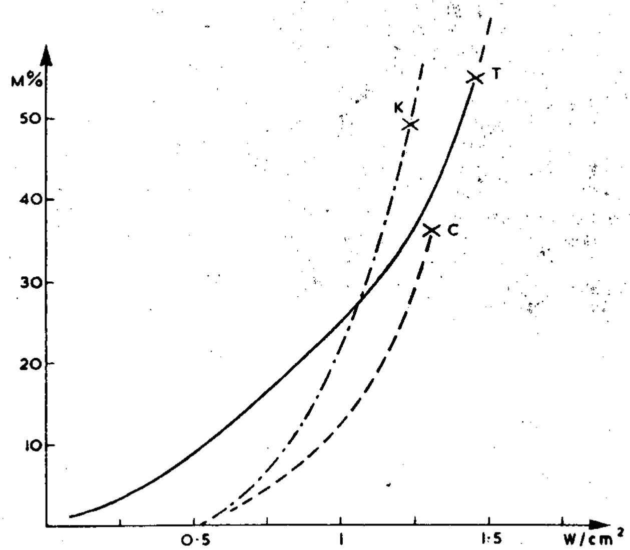

Fig. 2. Principal US effects are the temperature (T), the cavitation (K) and the chemical (C) effects. Increase of the metabolic factor M in per cent (ordinate) against US intensity in W/cm² (abscissa) in a typical experiment is shown

see that the cavitation and the chemical effect start after a delay, at about 0·6 W/cm² of intensity.

In the course of our experiments we were often able to observe the fact that temperature differences were mostly concentrated in the inter-boundary layers, especially when the latter carried an electric charge. We experimented with gel phantomes of different electric conductivities, by treating them chemically, and with plastic particles such as Polyvinyl-chloride, which are neatly spherical, and into which we introduced thermo-sensitive colourchanging chemicals ($CoCl_2$ and HgI_2). Figs. 3 and 4 show the specific thermal effect. When the interboundary space was electrically distorted, either by the introduction of plastic films, as shown in Fig. 3, or by chemically acting substances, such as wetting agents, the temperature pattern changed considerably. This proves that a sudden change in the electrical field concentration produces high temperature gradients in areas which could never be heated up by conventional caloric means. Thus, for example, microbe suspensions, when agglomeration clusters and air or gas bubbles are present, may be killed at temperatures which ordinarily support life.[15] This would appear to be an electrical, non-thermic effect. However, it is a specific-thermal effect combined with chemical effects in US fields.

When we measure the temperature of the microbe suspension with a thermometer, we measure only its average temperature and not the local temperature of the microbes, which is much higher under favourable irradiating conditions.

There are known electrical, non-thermic effects of MW,[20] for example, the molecular dipole effects, relaxation effects, ionic conductivity effects and induction effects (pearl-chain effects[21–4, 11–12]). The first three are frequency dependent, the last one is not. However, these are physical effects and no proof as yet exists that they have biological consequences, and if they do, that these consequences are more important than the Joule or specific-thermal effects which are present at the same time.

The pearl-chain effect occurs also in low frequency fields,[21, 22] even in technical alternative fields. Particles in suspension are polarized by

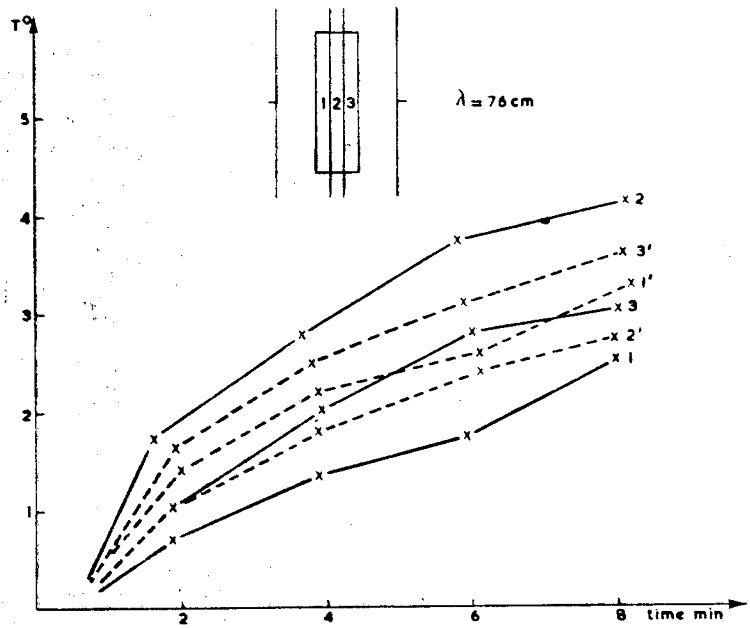

Fig. 3. Temperature rise in a heterogeneous object placed in a microwave condenser field. Three layers of a gel phantom having different electric conductivity show different temperatures T after irradiation in time. When they touch each other (broken line) and when they are separated by plastic sheets (solid line), the specific-thermal effect is different because of the discontinuity of the field in the interboundary space

induction, and align in chain-like formations.[21] The alignment is not always parallel to the field lines. The polarizing effect on the particles may lag behind the inducing alternative field, so that the particles align at an angle to the field forces. By changing the frequency, it is possible to change the aligning angle, or even produce in certain field configurations, circular polarized particles. This pearl-chain effect can be produced with any kind of particle, e.g. fat globules, erythrocytes, plastic globules (PVC), fish eggs, plant cells, etc., at low field intensity and as long as the viscosity of the liquid and the Brownian motion or any kind of thermal motion does not interfere with the induction forces.[11, 12]

Looking over all the above-mentioned physical and biological effects, we consider the specific-thermal effect and the chemical effect to be the most significant and the most dangerous of the health hazards. Their destructive force is evident, especially in non-homogeneous h.f. fields, i.e. in diffused and radiating fields (radar). As for US, the evolution of Sonar and other industrial applications may bring about some health hazards also.

Is it possible to shield an object against these forces? On the whole, yes. Here we must remember that the shielding metal or screen must be so chosen dimensionally that no harmful resonance effects with field concentrations on the body can be produced. The most vulnerable parts of the body are

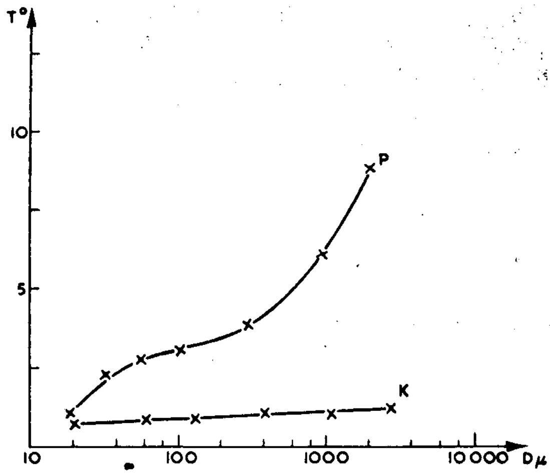

Fig. 4. Specific-thermal effects in particle agglomerations. The abscissa shows the diameter D *of the agglomeration in* μ. *The temperature rise* T *in 2 min is shown on the ordinate. The temperature curve of the liquid is* K *and the temperature curve of the agglomeration is* P. *The particles, about* 5μ *dia, are made of polymerized Polyvinyl. The clusters are separated by a distance of about five times the diameter* D. *The preparation was made in studies under the microscope, the temperature was measured by tiny thermocouples and by incorporating thermo-sensitive colour-changing chemicals in the particles and in the surrounding liquid*

the eyes, the ears and the glands, where heterogenous and semi-liquid conditions, as well as gas bubbles, respond favourably to specific-thermal effects of a destructive nature. This is valid for MW as well as for US fields. Though US fields of high frequency do not propagate easily over long distances outside the transducer area, yet those of lower frequency (under 600 kc/s) may travel along solid propagating media, such as pipes, to distant areas and accumulate in discrete points or areas through resonance conditions to higher energy levels. Bringing the body into contact with these resonant areas could induce health hazards.

In this connection, I should like to mention some " directional " effects of radiating fields. When a body or parts of a body are aligned parallel to the inducing field, a resonance effect may take place under favourable conditions, such as " dimensional tuning-in ". For example, a body having about the length or multiple of the length of the wavelength of the radiating field may be brought to resonance, and field concentrations of a dangerous level may result.

CONCLUSION

Joule and specific-thermal effects prevail in US and MW fields. Electrical effects, especially in MW fields of more than 1 W/cm^2 or of high-voltage gradients, are biologically possible, but not certain, though their physico-chemical existence has been known for a long time, under the form of polar, molecular and ionic anomalic behaviour. Pearl-chain effects are non-thermal, electric effects which can be induced in low energy fields independently of the frequency. Their biological importance is not yet established.

Specific-thermal effects are prone to occur where there are field irregularities and field concentrations, as well as where there are directional resonance effects. Imperfect screening may be more harmful than protective.

REFERENCES

1. Kowarschik, J., " Kurzwellentherapie ", Springer, Vienna (1950).
2. Saidman-Meyer, J., " Les ondes courtes en thérapeutique ", Doin, Paris (1951).
3. Groag, P., and Tomberg, V., " Zur Kurzwellentherapie ", *Wien. klin. Wochschr.*, *30*, 436 (1933).
4. Pohlman, R., " Ultraschalltherapie ", Verlag Hans Huber, Berne (1951).
5. Liebesny, P., " Athermic short-wave therapy ", *Arch. Phys. Therapy*, *19*, 736 (1938).
6. Heller, R., " Lokalisierte Durchwärmung mittels Ultra-Kurzwellen ", *Z. ges. exptl. Med.*, *83* (1932).
7. Schweinburg, F., " Uber die Beeinflussung des Wuterregers im Kurzwellengebiet ", Acta (Referate und Mitteilungen) of 1st Internat. Congress on Short Waves, p. 237, Verlag Brüder Hollinek, Vienna (1937).
8. Groag, P., and Tomberg, V., " Zur biologischen Wirkung kurzer elektrischer Wellen ", *Wien. klin. Wochschr.*, *9* (1934).
9. Groag, P., " Kurzwellentherapie, eine spezifische Wärmetherapie ", Acta (Referate und Mitteilungen) of the 1st Internat. Congress on Short Waves, p. 343, Verlag Brüder Hollinek, Vienna (1937).
10. Tomberg, V., " Punktwärme-effekte in Kurzwellenfeld ", *Sitzber. Wien. Med. Ges.* (1930).
11. Tomberg, V., " Bases scientifiques et conceptions nouvelles de l'utilisation des ondes courtes en therapeutique ", *Acta Physiother. Rheumat. Belg.*, *4*, 109 (1947).
12. Tomberg, V., " Leffet destructif des micro-ondes en biologie ", *Acta Physiother. Rheumat. Belg.*, *6*, 295 (1948).
13. Tomberg, V., " Les effets biologiques des ultrasons ", *Congr. intern. biochim.*, *2^e^ Congr.*, Paris (1952).
14. Tomberg, V., " Ultrasonic dosimetry for medical and biological use ", I.R.E. Congr., New York (March 1957).
15. Haase, S. E., " Versuche über den Einfluss kurzer elektrischer Wellen auf das Wachstum von Bakterien ", *Strahlentherapie*, *40*, 133 (1931).
16. Tomberg, V., " Spezifische Wirkungen kurzer elektrischer Wellen ", *Sitzber. Biophys. Ges. Kurzwellenforschung*, Vienna, *21* (Nov. 1934).
17. Tomberg, V., " Die Spezifisch Biologische Wirkungen kurzer elektrischer Wellen ", *Acta Congr. Radio-Biol.*, Venice, *1* (1934).
18. Tomberg, V., " Verteilung, Absorption und Messung der Energie im Kurzwellenfeld ", Acta (Referate und Mitteilungen) of 1st Internat. Congr. on Short Waves, pp. 155, 319, Verlag Brüder Hollinek, Vienna (1937).
19. McLennan, R., " The heating effect of short radio waves ", *Arch. Phys. Therapy*, 143 (1931).
20. Stieböck, P., lecture in *Wien. klin. Wochschr.*, 27 (1930).
21. Krasny-Ergen, W., " Mechanische Wirkungen der Kurzwellen ", Acta (Referate und Mitteilungen) of 1st Internat. Congr. on Short Waves, p. 180, Verlag Brüder Hollinek, Vienna (1937).
22. Muth, E., " Über die Erscheinung der Perlschnurkettenbildung von Emulsions-partikelchen unter Einwirkung eines Wechselfeldes ", *Kolloid-Z*, *41*, 97 (1927).
23. Blüh, O., " Einige bei der Untersuchung von Kolloiden im Wechselfeld autretende Erscheinungen ", *Kolloid-Z*, *37*, 267 (1925).
24. Denier, A., *Arch. électricité médicale* (March–April 1935).