EFFECTS OF CONTINUOUS AND PULSED MICROWAVE IRRADIATION ON DISTRIBUTION OF HEAT IN THE GLUTEAL REGION OF MINIPIGS

A Comparative Study

E. Conradi and Ines Helen Pages

From Humboldt-Universität zu Berlin, School of Medicine (Charité), Department of Physiotherapy (Director: MR Prof. Dr sc. med. E. Conradi), Berlin, German Democratic Republic

ABSTRACT. Eleven experiments were conducted on minipigs for the purpose of determining heat distribution in tissue exposed to therapeutic doses of microwaves. Tempertures were measured by means of coated thermocouples from the cutis, subcutis, musculature, and periost. Irradiation was applied to intensities of 10 W, 40 W and 60 W by means of a "Radarmed 12 S 251" circular emitter and to 60 W, 100 W and 140 W, using a trough emitter. Maximum temperature in superficial tissue layers was reached after five to ten minutes of microwave exposure. The temperature rise in the cutis and subcutis was steeper and at a higher rate than that in the muscles. Continuation of microwave irradiation did not cause any further rise in temperature, which was attributed to induction of hyperaemia. No difference regarding heat distribution was found to exist between pulsed and continuous irradiation at equal wattage.

Key words: pulsed therapy, microwave therapy, temperature measurement.

The introduction by Schliephake in 1928 of highfrequency energy for thermotherapy had paved the road to selective heating even of circumscribed tissue layers in deeper locations. Stimulation of blood circulation is one of the major therapeutic objectives, as in any kind of thermotherapy.

However, today high-frequency therapy has come to be used for adjuvant tumour treatment, taking into consideration that the thermal resistance of tumour cells is lower than that of normal tissue.

Hence, a distinction ought to be made between conventional heat treatment for usually painful diseases (6, 8, 12, 15) and locally delimited hyperthermia in tumour therapy (1, 5, 7, 9, 11, 13, 21, 22).

Knowledge about the course of heating in living tissue is essential to scientifically substantiated thermotherapy. True, typical heat distribution patterns in response to short waves and microwaves had been reported in 1953 by Pätzold (20). Studies of temperature time curves were, however, not undertaken until more recently among others by Lehmann (15) and McNiven (18). Those studies indicated changes of blood circulation.

A pulsed-operation variant of high-frequency therapy has later been published (2, 19, 23). It has been suggested that blood circulation can increase by pulsed short-wave therapy without tissue heating (10). We have done a pilot study to test the temperature courses in tissue at various intensity levels with comparison of continuous and pulsed microwave irradiation. Implementation of such tests depended on the availability of a microwave emitter which guaranteed emission of identical doses per unit time for both operation variants.

METHODS

We used eleven Mini-Lewe pigs, between 34 kg and 50 kg in body weight and aged three to four months. That species was found to be suitable for the experiments since the tissue layer dimension and thermoregulatory conditions in these animals are similar to those in man (17). Irradiation was applied to the gluteal region, using a "Radarmed 12 S 251" circular emitter (supplied from Fa. Robert Bosch GmbH). This unit releases 2450 MHz ± 50 MHz both continuous and pulsed microwaves. The long-time output in continuous operation is 250 W maximum. In pulsed operation, the peak intensity of one single pulse amounts to 1600 W. Intervals between pulses depended on preselected intensities. Doses were 40 W and 60 W for continuous and pulsed irradiation, when the circular emitter was used, whereas 10 W were released only in pulsed operation. The circular emitter for all experiments was placed 10 cm from the skin surface of the animal. The trough emitter was used for 60 W, 100 W, and 140 W, with the emitter being directly applied to the treated region and being kept in contact with the skin surface. Irradiation lasted 20 min.

The minipigs were kept under potentiated venous anaesthesia via the ophthalmic sinus, using a combination of ketamine hydrochloride with Methitural.

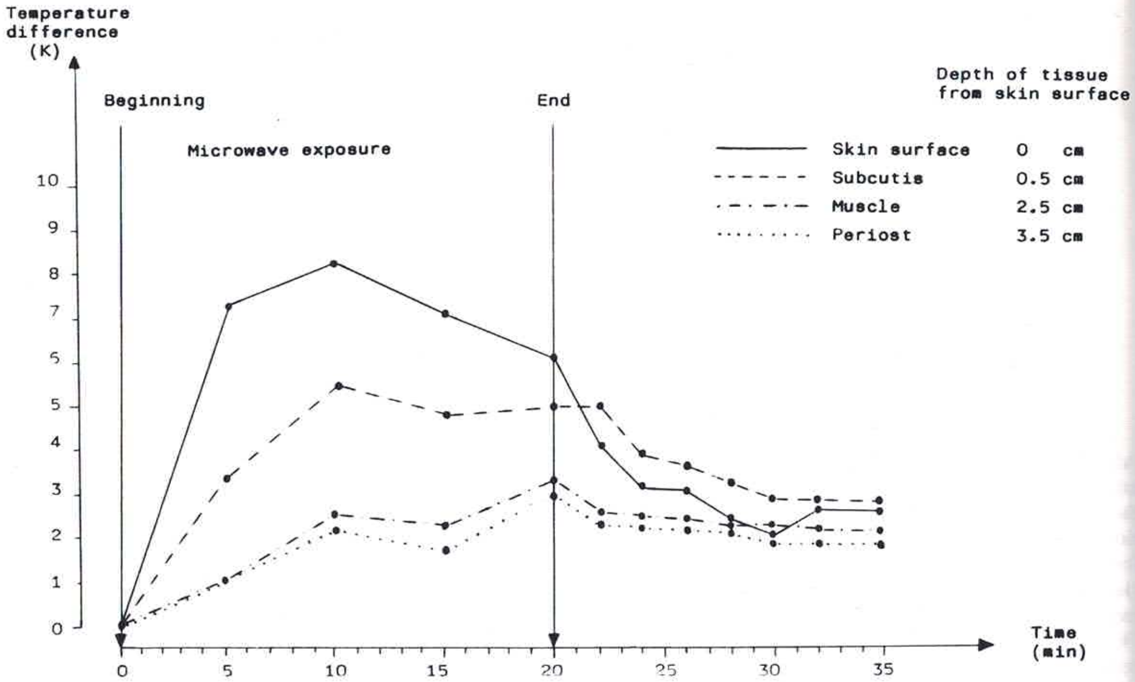

Fig. 1. Typical temperature courses in different tissue layers in response to continuous 60W microwave irradiation of gluteal region of a minipig, using circular emitter.

Temperature was measured by means of coated thermocouples, 0.15 mm in diameter, made of a chromium-nickel alloy (supplied from Fa. VEB Walzwerk Hettstedt). Metal objects inserted in tissue are likely to be heated beyond predictability by exposure to microwaves. Ways, therefore, had to be found by which to remove the coated thermocouples from the target area during irradiation. However, in order to reach the same point in tissue for repetitive measurement, plastic syringes were inserted into each of the tissue layers to act as guide tubules. Preparatory phantom experiments had been conducted beforehand to rule out additional heating of the plastic syringes, with no temperature difference being recorded from comparative measurements with and without such plastic syringes.

Measurements were applied to the skin surface, subcutis (0.5 cm), musculature (2.5 cm), and periost (3.5 cm).

After five minutes of microwave irradiation, the emitter was swung out of the respective field of measurement, whereafter the coated thermocouples were introduced into the plastic syringes and values read from the measuring unit. Irradiation used to be discontinued for that purpose for about 30 sec.

RESULTS AND DISCUSSION

Eleven temperature curves were obtained from the above measurement arrangement. The maximum rises in temperature at the measuring points in all tissue layers are given separately by circular and trough emitters (Tables I and II). No rise in core tempera-

Table I. *Maximum rise in temperature (T_{max}), following pulsed and continuous microwave irradiation at 10 W, 40 W, and 60 W of gluteal region of minipigs (n=5), using "Radarmed 12 S 251" circular emitter*

Animal no.	Intensity (watts)	Mode of operation	Cutis	Subcutis	Muscles	Periost
1	10	⊓⊔⌐	3.5	1.2	0.4	0
2	40	⌐‾	8	6	2.1	2.8
3	40	⊓⊔⌐	8.5	4.2	1.3	1.2
4	60	⌐‾	8.7	5.6	3.3	3.1
5	60	⊓⊔⌐	8.2	5.5	2.3	1.2

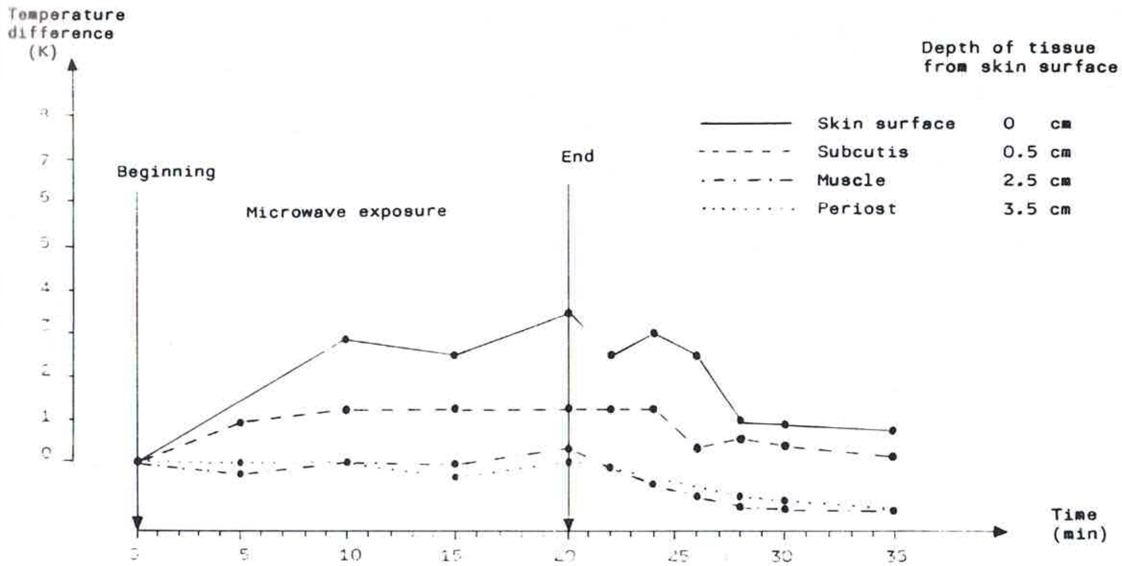

Fig. 2. Temperature courses in different tissue layers in response to pulsed 10-W microwave irradiation of gluteal region of a minipig, using circular emitter.

ture of the body was recorded from below-scapula measurements. A typical temperature curve, following continuous microwave irradiation of 60 W by circular emitter, is depicted as an example in Fig. 1. Peak values of temperature rise were reached in cutis and subcutis not later than 10 min after start of exposure. Temperature rises were flatter and at lower rates in muscles and periost, with peak levels béing reached in either layer only after 20 min of exposure, at which time a plateau or even temperature drop was beginning to develop in cutis and subcutis. Plateau formation, according to Lehmann (15, 16), is attributed to the onset of hyperaemia, obviously beyond a threshold that should be defined as 40°C for muscles.

The temperature rise in both cutis and subcutis was substantially higher than those in muscles and periost with both applications and modes of irradiation (pulsed and continuous). Muscle and periost values accounted for as little as 30 or 40%, as compared to subcutis. Hence, the authors' results differ from the phantom data reported by Pätzold (20).

The temperature rise was depending on irradiated energy level. No heating occurred in deeper cutaneous layers as a result of the very low intensities, for example, 10 W by circular emitter or 60 W by trough emitter. Such dosage, however, must not be defined as "athermic". Any influence on blood circulation, as had been observed by Jenrich (10) in the context of "athermic" dosage, was not recorded in our experiments (Fig. 2).

No difference was found to exist between pulsed

Table II. *Maximum rise in temperature (T_{max}), following pulsed and continuous microwave irradiation at 60 W, 100 W, and 140 W of gluteal region of minipigs (n=6), using "Radarmed 12 S 251" trough emitter*

Animal no.	Intensity (watts)	Mode of operation	Cutis	Subcutis	Muscles	Periost
1	60	⌐	4.1	2.6	0	0
2	60	⎍⎍	6.5	2.7	0.6	0.7
3	100	⌐	6.6	4.4	0.8	0.5
4	100	⎍⎍	5.6	4.1	1.2	0
5	140	⌐	8.5	8	3.5	3.5
6	140	⎍⎍	10.1	10	2.3	3.2

and continuous irradiation at identical energy level. The temperature was, however, dependent on the type of emitter: The temperature values in muscles and subcutis, using the circular emitter, were somewhat higher than those resulting from the trough emitter.

REFERENCES

1. Ardenne, M. v.: On a new physical principle for selective local hyperthermic of tumor tissues. In: Cancer Therapy by Hyperthermic and Radiation (ed. Streffner et al.), pp. 96–104. Urban & Schwarzenberg, Baltimore, 1978.
2. Barker, A. T., Barlow, P. S., Proter, J., Smith, M. E., Clifton, S., Andrews, L. & O'Dowd, W. J.: A double-blind clinical trial of low power pulsed shortwave therapy in the treatment of a soft tissue injury. Physiotherapy (London) *71:* 500–504, 1985.
3. Böni, A. & Lotmar, R.: Temperaturmessungen an tierischen und menschlichen Geweben nach Bestrahlung mit Mikrowellen. Arch Phys Ther Leipzig *4:* 174–202, 1952.
4. Braun, M. & Dhom, G.: Tierexperimentelle Untersuchungen mit Mikrowellen. Strahlentherapie (Munich) *99:* 617–623, 1956.
5. Dietzel, F.: Tumor und Temperatur. Aktuelle Probleme bei der Anwendung thermischer Verfahren in der Onkologie und Strahlentherapie. Urban & Schwarzenberg, Munich, Berlin, Vienna, 1975.
6. Edel, H.: Fibel der Elektrodiagnostik und Elektrotherapie. 3rd ed. Theodor Steinkopff-Verlag, Dresden, 1975.
7. Hand, J. W.: Review article. Heating techniques in hyperthermics. Br J Radiol *54:* 443–446, 1981.
8. Hentschel, H. D. & Rusch, D.: Arch Phys Ther (Leipzig) *21:* 287, 1969.
9. Hornbach, B., Shupe, R. et al.: Radiation and microwave therapy in the treatment of advanced cancer. Radiology *130:* 459–464, 1979.
10. Jenrich, W.: Impulskurzwellentherapie. Wirkungsweise und Anwendungen. Elektromedica *53:* 165–168, 1985.
11. Kenneth, H. et al.: The use of 2 450 MHz of microwave in cancer therapy. Phys Ther *59:* 405–408, 1979.
12. Koenig, G.: Besonderheiten der Dezimeterwellentherapie. Medizintechnik *9:* 103–106, 1969.
13. Kopecky, W. J. et al.: A microwave hyperthermia treatment and thermometry system. Int J Radiat Oncol Biol Phys *5:* 2113–2115, 1979.
14. Kuttig, H.: Die Mikrowellen und ihre physikalischen und biologischen Grundlagen. Elektro-Med (Berlin) (W) *3/7:* 201, 1958.
15. Lehmann, J. V., Silbermann, D. R., Braun, B. A., Kirn, N. L. & Johnston, V. C.: Temperature distributions in the human thigh produced by infrared, hot pack and microwave applications. Arch Phys Med *47:* 291, 1966.
16. Lehmann, J. V. et al.: Therapeutic heat and cold. 3rd ed., pp. 404–562. Williams & Wilkins, Baltimore/London, 1982.
17. Leucht, W., Gregor, C. & Stier, H.: Das Miniaturschwein—Versuchs- und Modelltier in Medizin und Biologie. VEB Gustav Fischer-Verlag, Jena, 1982.
18. McNiven, D. R. & Wyper, D. J.: Microwave therapy and muscle blood flow in man. J Microwave Power *11:* 168–170, 1976.
19. Pasila, M., Visuri, T. & Sundhohm, A.: Pulsating shortwave diathermy: Value in treatment of recent ankle and foot sprains. Arch Phys Med Rehabil *59:* 383–386, 1978.
20. Pätzold, J.: Die biologischen Grundlagen der Kurzwellentherapie unter Berücksichtigung der sogenannten Mikrowellentherapie. Strahlentherapie (Munich) *92:* 308, 1953.
21. Raymond, U. et al.: Microwave-induced local hyperthermia in combination with radiotherapy of human malignant tumors. Cancer *45:* 638–646, 1980.
22. Taylor, L. S.: Brain cancer therapy. Using an implanted microwave radiator. Microwave J 66–71, 1981.
23. Wilson, D. H.: Treatment of soft-tissue injuries by pulsed electrical energy. Br Med J *2:* 269–270, 1972.

Address for offprints:

MR Prof. Dr sc. med. E. Conradi
Humboldt-Universität zu Berlin School of Medicine (Charité)
Department of Physiotherapy
Monbijoustr. 2
Berlin 1040, GDR