

ESHO quality assurance guidelines for regional hyperthermia

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The Technical Committee and the Clinical Committee of the ESHO evaluated the experience of the institutes which are active in clinical regional hyperthermia using radiative equipment. Based on this evaluation, QA guidelines have been formulated. The focus of these guidelines lies on **what** must be done not on **how** it should be done. Subjects covered are: treatment planning, treatment, treatment documentation, requirements and characterization of equipment, safety aspects, hyperthermia staff requirements and instrumentation for quality assurance.

1. Introduction

In the Netherlands the clinical efficacy of loco-regional HT as adjuvant to RT in advanced pelvic tumours has been demonstrated in a large prospective randomized trial for heat induced by radiative RF-techniques (van der Zee and van Rhooon 1993). Due to this encouraging result and the positive outcome of the ESHO melanoma trial (Overgaard *et al.* 1995) and the ESHO/MRC trial on localized superficial breast cancer (Vernon *et al.* 1996), it is expected that the clinical interest in loco-regional deep heating by radiative RF-techniques will increase in the next few years. At this point, the Technical Committee and the Clinical Committee of the ESHO decided to evaluate the experience of the institutes which are active in clinical hyperthermia. Based on this evaluation, QA guidelines have been formulated. Strict confirmation to these guidelines is necessary to ensure therapeutic impact and further expansion of hyperthermia.

The guidelines are mandatory for all hyperthermia treatments in the framework of ESHO trials, which aim to treat tumours in the *pelvic area* by *radiative radio-frequency* equipment. Designed to treat loco-regionally, these systems are available as, a.o. the BSD 2000 system (Turner and Schaeffermeyer 1989), the Amsterdam four waveguide system (van Dijk *et al.* 1990) and the Coaxial TEM system (de Leeuw and Lagendijk 1987). With these systems treatment is considered loco regional (see appendix 1). An essential characteristic of these loco-regional hyperthermia devices is that they generate a circumferential electric field distribution around the patient, directed parallel to the body axis and use the interference principle to achieve high

power deposition at the centre of the body with minimal heating of the subcutaneous fat tissue. All other loco-regional hyperthermia systems like capacitive, inductive or ultrasound ones will need separate evaluation by the Technical Committee of the ESHO before they can be used within ESHO clinical trials.

For ESHO trials these guidelines replace the RTOG guidelines for hyperthermia of deep-seated malignancies (Dewhirst *et al.* 1990, Sapozink *et al.* 1991).

Even more than in the quality assurance guidelines for ESHO protocols for superficial electromagnetic heating techniques (Hand *et al.* 1989), the focus of this report lies on *what* must be done not on *how* it should be done. Throughout the guidelines use of the word *must* implies that compliance with a procedure is mandatory. Use of the word *should* implies that compliance with a procedure is in line with good practice.

2. Treatment planning (what to do before the individual treatment starts)

- The tumour must be localized using CT and/or MRI.
- Routine calculation of temperature distributions for clinical treatments is not yet available. Treatment planning of the 3D absorbed power distribution (SAR) has not yet reached the status of maturity. Further research in this field is encouraged. The clinical use of present 3D treatment planning systems is highly recommended; they provide insight in possibilities and limitations of SAR control and may help in defining system settings (appendix 2).
- Present 2D planning systems do not provide reliable phase and amplitude values and must thus not be used to define the initial system settings. If 3D planning values are absent it is recommended to start the first treatment with equal phase and amplitude settings.
- Based on patient anatomy, system characterization, thermometry feasibility and experience, a decision must be made whether the patient can be treated.
- A treatment prescription must be made and should, among others, contain: tumour temperature goal, upper limit normal temperatures, bolus temperatures, initial temperature increase, upper limit total power, starting power, definitions start and stop of treatment, treatment duration, number of treatments, maximum systemic temperature, maximum heart rate, min/max blood pressure.
- A careful documentation of relevant variables (particularly temperatures and side effects) by the responsible physician and physicist (physical engineer) must be made. Their interrelationship with input parameters (phase, amplitudes, frequency, cooling, etc) and the details of the system setup gives the basis for the subsequent heat treatment.

3. Treatment

- Mechanical patient setup must be quantified, with an accuracy of 1 cm.
- Bolus extension (additional water bags) must be applied when the patient complains about localized pain at the bolus edges.
- Multi-sensor probes and/or thermal mapping systems must be used. Preferably at least one multi-sensor probe or thermometry track should be positioned in the tumour. At least one sensor must be tumour related; this implies positioned in the tumour or directly adjacent to the tumour. This sensor will be used to define the initial temperature rise and thus the SAR in the tumour area (appendix 3).

- Thermometry sensors must be positioned intraluminal in bladder, rectum and vagina when available. For cervix tumours also a catheter should be placed in the lumen of the cervix and uterus. If tumour sites outside the pelvic area are being treated intraluminal sensors will not be available and invasive tumour thermometry must be applied.
- Radiographs or CT or other techniques must be used to demarcate the sensor locations.
- Power and phase levels must be measured at least every minute.
- Stationary thermometry sensors must be measured at least every minute. In case of mapping systems a scan must be made every 5 min. If the length of the thermometry track is > 15cm a scan may be made every 10min.
- Initial temperature rise in the tumour related sensor points should be above 0.2°C per min but must not exceed 1°C per min.
- In the case of thermocouple thermometry the first two temperature measurements must be analysed to ensure absence of selfheating and thermometry disturbance (appendix 4).
- SAR measurement during treatment, using *in vivo* E-field probes and/or thermal pulse techniques is highly recommended and will help in obtaining optimal system settings (appendix 3).
- During treatment normal tissue temperatures above 44°C should not be accepted. Fat tissue is an exception, 45°C may be accepted without an acceptable increase of the risk for thermal damage. The limited thermometry gives no guarantee that high temperatures will not occur, prevention of treatment related pain is the major way to prevent thermal damage to normal tissue.
- Unfortunately, most treatment will be limited by normal tissue temperatures and/ or systemic stress. The tumour temperatures goal is 43°C but higher temperatures can be accepted depending on the clinical situation.
- Systemic temperature must be monitored at least every 15 min via an oesophageal probe at the level of the eight thoracic vertebrae or orally (appendix 5). If the treatment goal is to optimize local tumour temperatures by systemic temperature elevation it is recommended to use an oesophageal probe and to measure systemic temperature at least every 5 min.
- Systemic temperature should not exceed 40°C (appendix 6).
- Additional cooling to limit the systemic temperature or improve patient comfort should be applied to an extent which is comfortable for the patient, preferably by cooling thorax, forehead and face.
- Non-invasive procedures must be used to monitor blood pressure and heart rate every 5 min. A more frequent monitoring of the heart rate, for instance through a pulse oximeter or an ECG-monitor which has been made immune to RF stray fields, is recommended.
- Bladder temperature must be controlled (appendix 7).
- Because pain sensation is of major importance to prevent normal tissue damage the use of analgesic medication should only be used to suppress pre-existing pain from clinically known sites.
- In the protocols the start and duration of treatment must be defined. A possible definition of the point of time of the treatment start is the minute in which a tumour related sensor reaches 41°C or 30 min after power switched on.

4. Treatment documentation

- A computerized data acquisition system should be used,
- All primary thermometry data must be stored, however, treatment may be summarized using temperature parameters (normal tissue temperatures, tumour temperatures also in terms of T90, T50, T10), and
- Data storage should be preferably in the HDS format (Sapareto *et al.* 1995).

It is recommended that the following details be recorded on the treatment form:

- Patient and tumour characteristics,
- System used, mechanical set-up, patient position, bolus configuration, additional boluses, etc.,
- System settings: frequency, phase, amplitude, power (forward and reflected) and any changes during treatment in these settings,
- Thermometry used and location of thermometry sensors and mapping tracks,
- Possible occurrence of temperature artifacts,
- Intraluminal temperatures, tumour temperatures, normal tissue temperatures, systemic temperature, bolus temperature,
- Bladder irrigation if applied,
- All measures applied for cooling,
- Hemodynamic parameters (HR, blood pressure),
- Treatment duration,
- Acute toxicities; the occurrence, nature and duration of any discomfort and pain and whether this pain is power, bolus pressure or patient positioning related, and
- The occurrence of treatment limiting factors, discontinuity of treatment, with reasons.

5. Requirements and characterization of equipment

- The accuracy of the equipment used in the amplitude, phase and power verification procedures must be verified by an independent measurement method.
- A phase accuracy of the heating system of 10 degrees at the applicator(s) feed point must be obtained (appendix 8).
- An accuracy of the absolute power level of 10% of the actual value must be obtained.
- System performance must be checked regularly using the LED matrix/lamp phantom using different phase/amplitude settings, different phantom positions and different bolus configurations (Schneider and van Dijk 1991, Schneider *et al.* 1994, Wust *et al.* 1994, 1995a).
- System efficiency should be checked using a thermal method (appendix 9).
- The accuracy of patient positioning should be 1 cm.
- A schedule for periodic system maintenance and control must be present and a logbook must be kept.
- The accuracy of any thermometer must be 0.2°C or better within the range of 37-46°C.
- The stability of any thermometer must be 0.2°C or better over the duration of a treatment.
- All thermometers must be calibrated against a temperature standard which is accurate to 0.02°C and traceable to a National Standard. This calibration could

be made by using at least two calibrated mercury thermometers and a stirred water-bath with appropriate temperature uniformity and stability.

- The thermometry system readings must be verified at a regular base at a single temperature point within the clinical range of 41-42°C; system stability must be documented.
- The thermometry system must be checked in the phantom situations for the occurrence of rf disturbance (appendix 4).
- The positioning of the thermal mapping technique should be checked periodically.
- The accuracy of the sensor positions of multi sensor thermocouple probes should be checked periodically.

6. Safety aspects

- Safety devices should be incorporated to prevent overheating of the patient; in case of thermometry or computer failure the heating system should be shut off automatically.
- A good audible and visual contact with the patient must exist. The patient provides essential information with regard to power control and his/her general condition. Any information about pain sensation, discomfort or other feelings related to the hyperthermia treatment must be directly forwarded to the treatment team.
- It is recommended that a thorough inventory is made of the maximum intensities of stray radiation that may occur during treatment for different patients and conditions. The maximum tolerable levels of stray radiation are determined by the national authorities (appendix 10).
- Presence of surgical clips is a reason to omit hyperthermia treatment, but only if they are clustered densely (Lee *et al* 1992). Patients with metal implants and pacemakers should not be treated; if treated great caution must be taken.

7. Hyperthermia staff requirements

For hyperthermia treatments the responsible staff must consist of a physician and a physicist or physical engineer (Visser and van Rhoon 1995). The impact of the deep hyperthermia on the physiological condition of the patient, i.e. core temperature, pulse-rate, blood pressure and pain, is such that continuous supervision by the physician is highly recommended to ensure patient safety.

8. Instrumentation for quality assurance

The minimum set of QA-instrumentation must include a standard thermometer, a standard power meter, high power dummy loads, a vector-voltmeter, bidirectional couplers, a reliable precision waterbath, and standard tissue equivalent phantoms of symmetrical and elliptical shape. An additional frequency meter is recommended. The instrumentation is mainly required to ensure that the phase and amplitude relations at the applicators set by the hyperthermia system are indeed the values requested.

Appendix 1

Three strategies for homogenizing the temperature distribution during hyperthermia or deep seated tumours can be distinguished (Lagendijk *et al.* 1995):

- Blood preheating. The temperature uniformity in the tumour is improved by preheating the blood in the incoming vessels.
- Spatial control of the absorbed power distribution. Energy loss by cooling through the vasculature is compensated for by extra deposition at those locations.
- Short duration hyperthermia. By using short heating times and high temperatures the cooling influence of the vessels is limited to their immediate surroundings.

Although the second and third strategy are appealing with regard to the expected uniformity of the temperature distribution, it must be realized that SAR-control at a 1 cm^3 level is required (Lagendijk *et al.* 1994). Theoretically, this can be achieved only by very advanced ultrasound and interstitial heating devices. These devices are still under development and clinical experience is limited. Presently, only radiofrequency (RF) techniques are widely used for clinical treatments of deep seated tumours and have demonstrated their ability to induce regional heating in the pelvic area. These techniques come closest to the strategy of blood preheating, as large tissue volumes surrounding the tumour are heated and even systemic temperature rises. Therefore it is essential to deposit as much power as possible in the treatment volume by rf radiation. For this purpose power-limiting influences, such as hot spots, must be prevented by all available control parameters.

Appendix 2

Experience so far shows that 3D SAR-planning can be used to extract clinically relevant information, when it is used with great care. It also serves as an excellent platform for teaching new users the concept and the pitfalls of electromagnetic heating. Further research is needed towards the sensitivity of the SAR distribution to various patient and treatment system parameters. This should include development of models which include these parameters. Examples include the difference between contour-based and voxel-based models, tissue segmentation and their dielectric parameters, data truncation, the influence of patient position and attitude and the quantitative use of the planning systems.

Different modelling approaches and algorithms are under clinical research at present (Sullivan 1993, Paulsen *et al.* 1993, Nadobny *et al.* 1996, Hornsleth 1996).

Appendix 3

It is highly recommended to use the initial temperature rise of the thermometry sensors to get an impression of the SAR distribution. The phase and amplitude settings of the system may be evaluated using this initial temperature rise of all sensors, optimizing the temperature rise in the tumour related sensor(s). If the temperature rise of the tumour related sensor(s) is below 0.2°C a reasonable treatment is unlikely (Wust *et al.* 1995b). It is recommended that the design of the system software be modified to allow this type of testing procedure.

Appendix 4

Muti sensor thermocouple probes may be used for thermometry; however special precautions must be made to prevent self heating and rf disturbance. By analysing the first two pulses the occurrence of selfheating must be checked (De Leeuw *et al.* 1993).

Appendix 5

Systemic temperature measurements may be best performed by an oesophageal probe at the level of the eighth thoracic vertebrae. Oral measurements can be used but should be corrected by adding 0.5°C. Infrared tympanic thermometry is inaccurate and must not be used.

Appendix 6

Increased systemic temperature may improve temperature uniformity in the target volume. The use of systemic temperature between 38.5 and 40°C should be further evaluated. The use of systemic temperatures in the whole body hyperthermia range (41.8°C) should be considered with great caution because of the possibility of enhancing the risk of metastasis (Thrall *et al.* 1996). Research towards systemic temperature uniformity has to be extended. It is expected that systemic temperature uniformity may be increased by applying cooling if necessary as much as possible through the thorax, forehead and face and not through the legs, pelvis and abdomen.

Appendix 7

It is not recommended to limit the total power applied by high bladder temperatures. Higher tissue temperature may be obtained by controlling the bladder temperature; irrigating the bladder with deionized water or a saline solution is recommended in case of bladder temperatures above the prescribed bladder temperature.

Appendix 8

A vector voltmeter is a simple to use and reliable piece of equipment in the amplitude and phase verification process. By applying directional couplers it can be hooked to the heating system without any influence on the system performance. It is essential that phase and amplitude are measured between the power amplifier and the applicator(s) feeding points (Raskmark *et al.* 1994, Schneider *et al.* 1995b). The use of phased lock loop systems is highly recommended.

Appendix 9

A solid saline (3 gr/l) gel phantom can be used to measure the temperature rise after a short burst of power. Compared to the LED phantoms such a phantom gives absolute readings for the SAR (Schneider *et al.* 1995a). System efficiency can also be checked using a stirred liquid saline phantom.

Appendix 10

It should be verified whether the level of the EM-stray radiation is within the exposure restrictions as allowed by the national authorities with respect to exposure of workers and general public to non-ionizing radiation. Good literature on general measurement techniques and pitfalls in the measurement of radio frequency fields around the patient is provided in the NCRP report no 119 (1993). The required shielding of the hyperthermia treatment room depends on the stray radiation levels produced by the deep heating systems. It should be verified whether the level of the EM-stray radiation is below the maximum level allowed by the national authorities with respect to telecommunication and CE-requirements. A good reference is White (1986). Radiation survey meters should monitor both the magnetic and electric fields.

References

- DE LEEUW, A. A. C, and LAGENDIJK, J. J. W., 1987. Design of a deep-body hyperthermia system based on the 'Coaxial TEM' applicator. *International Journal of Hyperthermia*, 3, 413-421.
- DE LEEUW, A. A. C, CREEZEE, J., and LAGENDIJK, J. J. W., 1993. Temperature and SAR measurements in deep body hyperthermia with thermocouple thermometry. *International Journal of Hyperthermia*, 9, pp. 685-697.
- DEWHIRST, M. W., PHILLIPS, T. L., SAMULSKI, T. V., STAUFFER, P., SHRIVASTAVA, P., PALIWAL, B., PAJAK, T., GILLIM, M., SAPOZINK, M., MYERSON, R. WATERMAN, F. M., SAPARETO, S. A., CORRY, P. M., CETAS, T. C, LEEPER, D. B., FESSENDEN, P., KAPP, D. S., OLESON, J. R., EMAMI, B., 1990. RTOG quality assurance guidelines for clinical trials using hyperthermia. *International Journal of Radiation Oncology, Biology and Physics*, 18, 1249-1259.
- HAND, J. W., LAGENDIJK, J. J. W., ANDERSON, J. B., and BOLOMEY, J. C, 1989. Quality assurance guidelines for ESHO protocols. *International Journal of Hyperthermia*, 5, 421-428.
- HORNSLETH, S. N., 1996. Radiofrequency regional hyperthermia, PhD thesis, Aalborg University.
- LAGENDIJK, J. J. W., CREZEE, J., and HAND, J. W., 1994. Dose uniformity in scanned focused ultrasound hyperthermia. *International Journal of Hyperthermia*, 10, 775-784.
- LAGENDIJK, J. J. W., CREZEE, J., and MOOIBROEK, J., 1995. Principles of treatment planning. *Diagnostic Imaging and Radiation Oncology Thermochemistry and Thermochemotherapy, vol. 1.* edited by M. H. Seegenschmiedt and P. Fessenden (Heidelberg: Springer), pp. 439-451.
- LEE, E. R., SULLIVAN, D. M., and KAPP, D. S., 1992. Potential hazards of radiative electromagnetic hyperthermia in the presence of multiple metallic surgical clips. *International Journal of Hyperthermia*, 8, 809-817.
- NADOBNY, J. P., WUST, P., SEEBASS, M., DEUFLHARD, P., and FELIX, R., 1996. A volume-surface integral equation method for solving Maxwell's equations in electrically inhomogeneous media using tetrahedral grids. *IEEE Transactions of Microwave Theory and Techniques*, 44, 543-554.
- NCRP report no 119, 1993. *A practical guide to the determination of human exposure to radiofrequency fields.*
- OVERGAARD, J., GONZALEZ GONZALEZ, D., HULSHOF, M. C C. M., ARCANGELI, G., DAHL, O., MELLA, O., and BENTZEN, S. M., 1995. Randomised trial of hyperthermia as adjuvant to radiotherapy for recurrent or metastatic malignant melanoma. *The Lancet*, 345, 540-543.
- PAULSEN, K. D., JIA, X., and SULLIVAN, J. M., 1993. Finite element computations of specific absorption rates in anatomically conforming full-body models for hyperthermia treatment analysis. *IEEE Transactions of Biomedical Engineering*, 40, 933-945.
- RASKMARK, P., LARSEN, T., and HORNSLETH, S. N., 1994. Multi-applicator hyperthermia system description using scattering parameters. *International Journal of Hyperthermia*, 10, 143-151.
- SAPARETO, S. A., KNOL, R. G. F., CORRY, P. M., and SEEGENSCHMIEDT, M. H., 1995. Standardized thermoradiotherapy treatment documentation. *Thermoradiotherapy and thermochemotherapy, vol. 2, Clinical applications*, edited by M. H. Seegenschmiedt, P. Fessenden and C C. Vernon (Berlin: Springer), pp. 385-393.
- SAPOZINK, M. D., CORRY, P. M., KAPP, D. S., MEYERSON, R. J., DEWHIRST, M. W., EMAMI, B., HERMAN, T., PRIONAS, S., RYAN, T., SAMULSKI, T., SAPARETO, S., SHRIVASTAVA, P., STAUFFER, P., and WATERMAN, F., 1991. RTOG Quality Assurance guidelines for clinical trials using hyperthermia for deep-seated malignancy. *International Journal of Radiation Oncology, Biology, Physics*, 20, 1109-1115.
- SCHNEIDER, C. J., and VAN DIJK, J. D. P., 1991. Visualization by a matrix of light emitting diodes of interferences effects from a radiative four-applicator hyperthermia system. *International Journal of Hyperthermia*, 7, 355-366.
- SCHNEIDER, C. J., KUIJER, J. P., COLUSSI, L. C, SCHEPP, C. J., and VAN DIJK, J. D. P., 1995b. Performance evaluation of annular arrays in practice: the measurement of

- phase and amplitude patterns of radio-frequency deep body applicators. *Medical Physics*, 22, 755-765.
- SCHNEIDER, C. J., OLMI, R., and VAN DIJK, J. D. P., 1995a, Phantom Design Applicability and physical properties. *Thermoradiotherapy and thermochemotherapy, Vol. 1. Biology, Physiology and Physics*, edited by M. H. Seegenschmiedt, P. Fessenden and C. C. Vernon (Berlin, Springer), pp. 381-397.
- SCHNEIDER, C. J., VAN DIJK, J. D. P., DE LEEUW, A. A. C., WUST, P., and BAUMHOER, W., 1994. Quality assurance in various radiative hyperthermia systems applying a phantom with LED-matrix. *International Journal of Hyperthermia*, 10, 143-151.
- SULLIVAN, D. M., 1993. Stanford 3D hyperthermia treatment planning system. Technical review and clinical summary. *International Journal of Hyperthermia*, 9, 627-643.
- THRALL, D. E., PRESCOTT, D. M., SAMULSKI, T. V., ROSNER, G. L., DENMAN, D. L., LEGORETTA, R. L., DODGE, R. K., PAGE, R. L., CLINE, J. M., LEE, J., CASE, B. C, EVANS, S. M., OLESON, J. R., and DEWHIRST, M. W., 1996. Radiation plus hyperthermia versus radiation plus the combination of local and whole-body hyperthermia in canine sarcomas. *International Journal of Radiation Oncology, Biology, Physics*, 34, 1087-1096.
- TURNER, P. F., and SCHAEFFERMEYER, T., 1989, BSD-2000 approach for deep local and regional hyperthermia; Physics and technology. *Strahlentherapie und Onkologie*, **165**, 738-741.
- VAN DER ZEE, J., and VAN RHOON, G. C, 1993. The value of loco-regional hyperthermia in addition to a standard series of radiotherapy for the treatment of large, inoperable pelvic tumours. Final report of a study within the frame of Investigative Medicine, a program of the Dutch Health Insurance Fund Council.
- VAN DIJK, J. D. P., SCHNEIDER, C. J., VAN OS, R. M., BLANK, L., and GONZALEZ GONZALEZ, D., 1990, Results of deep body hyperthermia with large waveguide radiators. *Consensus on Hyperthermia in the 1990s*, edited by H. I. Bicher *et al.* (New York and London: Plenum Press), pp. 315-320.
- VERNON, C. C, HAND, J. W., FIELD, S. B., MACHIN, D., WHALEY, J. B., VAN DER ZEE, J., VAN PUTTEN, W. L., VAN RHOON, G. C, VAN DIJK, J. D. P., GONZALEZ GONZALEZ, D., Liu, F. F., GOODMAN, P., and SHERAR, M., 1996. Radiotherapy with or without hyperthermia in the treatment of superficial localized breast cancer: results from five randomized controlled trials. *International Journal of Radiation, Oncology, Biology, Physics*, 35, 731-744.
- VISSER, A. G., and VAN RHOON, G. C, 1995. Technical and clinical quality assurance. *Thermoradiotherapy and thermochemotherapy. Vol. 1 Biology, Physiology and Physics*, edited by M. H. Seegenschmiedt, P. Fessenden and C. C. Vernon (Springer), 453-472.
- WHITE, D. R. J., 1986. *Shielding Design, Methodology and Procedures* (Virginia, USA: Interference Control Technologies Inc, Don White Consultance).
- WUST, P., FAHLING, H., FELIX, R., RAHMAN, S., ISSELS, R., FELDMANN, H. J., VAN RHOON, G. C, and VAN DER ZEE, J., 1995a. Quality control of the SIGMA applicator using a lamp phantom: a 4-center comparison. *International Journal of Hyperthermia*, **11**, 755-767.
- WUST, P., FAHLING, H., JORDAN, A., NADOBNY, J., SEEBASS, M., and FELIX, R., 1994. Development and testing of SAR-visualization phantoms for quality control in RF hyperthermia. *International Journal of Hyperthermia*, 10, 127-142.
- WUST, P., STAHL, H., LOFFEL, J., SEEBASS, M., RIESS, H., and FELIX, R., 1995b. Clinical, physiological and anatomical determinants for radiofrequency hyperthermia. *International Journal of Hyperthermia*, 2, 151-167.