Novel applicator for local RF hyperthermia treatment using improved excitation control

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Abstract

In this paper, a novel applicator for hyperthermia treatment is presented providing a significantly improved quality assurance for the treatment. An improved method has been developed to measure the total incident field (amplitude and phase) and the power absorbed (SAR) by the tissues from each applicator element, based on integrated sensors and data acquisition electronics. For phased array deep RF hyperthermia this method can take into account reflection, mismatch, cross coupling and changes in any of these. Furthermore, a new treatment paradigm for superficial hyperthermia using deionised water as a dielectric waveguide to deliver power from each individual applicator to a specific region without significant impact on the divergence of the field with distance.

1. Introduction and Objectives

Studies have shown an increased efficacy of radiotherapy when combined with hyperthermia, while other studies have failed to show improvement. The variability can be attributed to poorly controlled hyperthermia application. This paper presents a system and treatment-planning system using new paradigms for enhanced quality assurance QA. The aim of hyperthermia is not thermal ablation, but to heat tumor to 42-44°C in order to increase the cell sensitivity to the effects of ionizing radiation. Heating is achieved using electromagnetic fields (EMFs) in the radio-frequency (RF) range generated by antennas placed outside the body. Improvement in the quality of a hyperthermia treatment can be obtained using patient-specific treatment planning with accurate patient and applicator models, accurately placing the applicator(s) relative to the patient, and ensuring treatment of the patient with the planned excitation signals. In this paper, a novel applicator for hyperthermia treatment is presented providing a significantly improved QA for the treatment. To assure the quality of a hyperthermia treatment, a number of steps must be performed, namely: patient-specific treatment planning with accurate patient and applicator models, applicator placement at the required location relative to the patient, and treatment of the patient with the planned exposure. Treatment planning is based on patient-specific images and uses dedicated software to optimize the treatment, considering the inhomogeneous tissue distribution and the local EM energy deposition, often non trivial due to the superposition of the fields from the applicator elements [1]. The application shown here is for soft-tissue sarcomas in animals.

2. Methods

An improved method has been developed to measure the total incident field (amplitude and phase) and the power absorbed (SAR) by the tissues from each applicator element. For phased array RF hyperthermia this method can take into account reflection, mismatch, cross coupling and changes in any of these. Furthermore a new treatment paradigm for superficial hyperthermia using deionised water as a dielectric waveguide to deliver power from each individual applicator to a specific region without significant impact on the divergence of the field with distance. Both can be the keys to providing effective treatment by ensuring that the treatment applied is the treatment that was planned.

An applicator is made up of a number of elements (Figure 1a) that are positioned around [1] or near the appropriate region containing the tissue or tumor to be treated. Energy is focused in to the tumor to raise its temperature, using phased array or SAR combining techniques, depending on tumor location.

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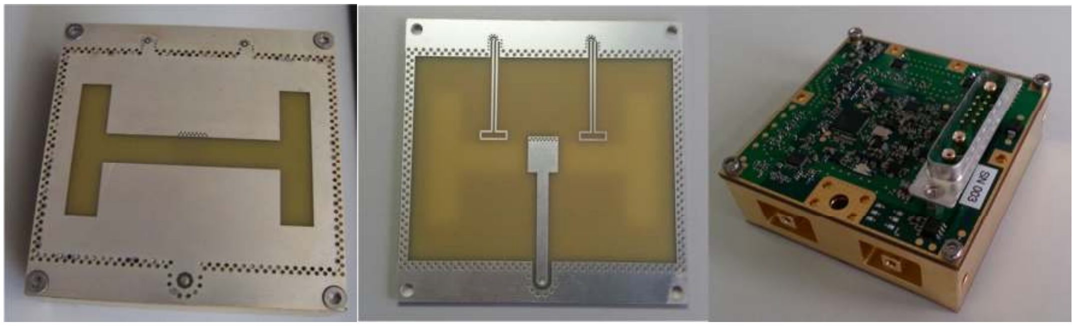
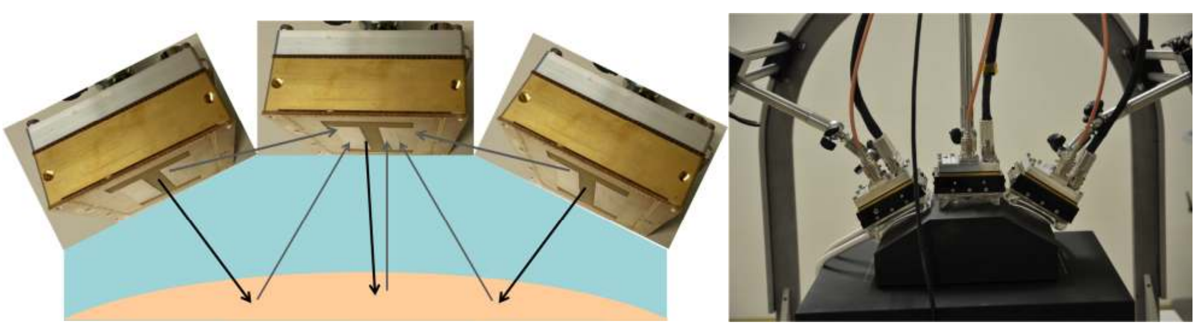


a) b) c)

Figure 1 a) Applicator element (Cavity backed slot), b) Feed and sensor structure inside the cavity, c) Full element with integrated data acquisition electronics.

Here a technique based on sensing the RF current flowing in each of the applicator elements is employed to determine the total field radiated (Figure 1b) due to both direct and coupled excitations of the elements. The sensor must be an integral part of the applicator element; use of a small loop or dipole in the vicinity of each element [2] does not meet the requirement due to it having direct coupling from other elements contaminating the measurement result. By placing the current sensors inside the cavity of the applicator element, direct coupling to fields from other elements is prevented. Therefore, it is possible to isolate the desired measurand. The element current is proportional to the total excitation and the total field radiated from the element, this measured quantity is equivalent to the ideal excitation in the absence of coupling, reflection etc. The system therefore implicitly corrects for the coupling and mismatch without explicit knowledge of, and calculation based on, the mutual coupling and mismatch, such that changes in the coupling and reflection due to presence of objects or changes thereof are inherently taken into account. In the presence of mutual coupling and reflections (Figure 2) the sensors measure the sum of all excitations, whatever their origin, and hence allow determination of the actual radiated field. Hence, the actual excitation vector for all the applicator elements can be compared to the required excitation vector and the feedback control facilitated. Furthermore, by exciting each element in turn and quantifying the currents flowing in each element as a result of each of the other elements, the coupling matrix for the entire array can be rapidly and accurately determined without the inaccuracies normally associated with S-parameter or other port measurement approaches [3]. The presence of variations in source impedance and undefined cable lengths are no longer important, excitation amplitudes and phases can be directly measured. Measured values in combination with the extracted coupling matrix allow calculations performed to rapidly adjust the excitation to the desired value to obtain the required total radiated field.

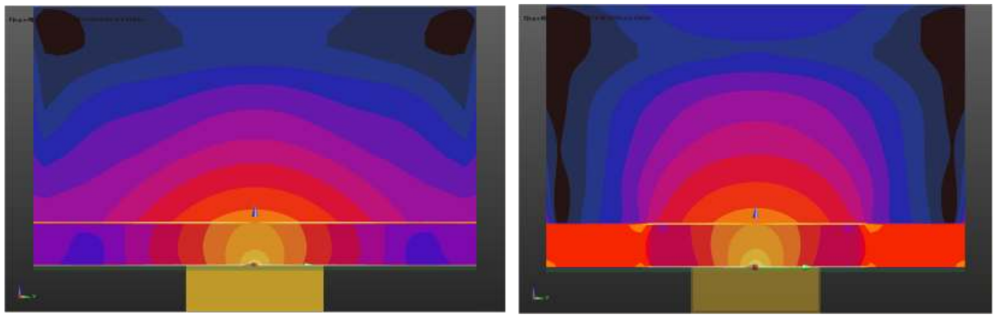


a) b)

Figure 2 a) Diagrammatic illustration of the excitations of the central element not directly related to the feed port excitation. b) Array being tested with a planar sensor array

Data acquisition electronics are integrated into each element for the measurement of current's amplitude and phase (Figure 1c). A differential phase reference signal is provided from the control and source electronics to lock the measurement system to the master clock ensuring ambiguity free evaluation of the radiated signal phase. A validation signal can be switched on to confirm correct operation of the measurement system and for use within a quality assurance framework for the treatment. The radiated field is directly proportional to the element current. Therefore, using measurements of the radiated field, calibration factors for the conversion of the current value into a field value are readily determined for each element and then stored on the element for recall whenever it is used.

The water bolus not only acts as interface from applicator to tissue and controls surface temperature, but affects the energy deposition patterns [4]. In the case of superficial hyperthermia, where SAR combining is used, the water bolus is used, not only to cool the body surface, but also as a dielectric waveguide [5], allowing the energy to be delivered to the target region without dispersion and hence to penetrate deeper into the body (Figure 3). The design of the applicator element allows full flexibility for the location, orientation, and number of elements to be used for a treatment. In combination with the developed treatment planning software, this new applicator enables to predict the power distribution and thermal load with sufficiently precision to reliably treat the tumor and to minimize unwanted hotspots in other areas.

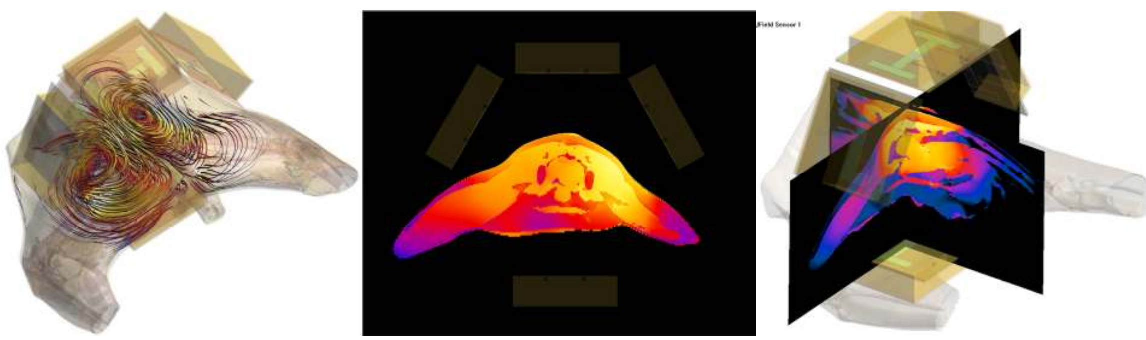


a) b)

Figure 3 SAR patterns 1dB per contour showing a) Case when the water bolus covers an extended area, b) water bolus configured as a dielectric waveguide confining and guiding the energy.

3. Results

Animal models with spontaneous soft-tissue sarcomas have been segmented, distinguishing tissues in and surrounding the region of interest including sensitive tissues. Numerical simulations were performed to plan the treatment, determining the optimal number of applicators for the treatment of regular shaped tumors located close to the surface, and developing treatment paradigms for more complex tumors, e.g., at joints, located close to sensitive organs or deep seated tumors. The Figure 4 shows the treatment for a feline deep seated tumor using a phased array of 4 applicators.



a) b) c)

Figure 4 a) Stream line view of applicator fields, b) SAR deposition pattern slice view and c) 3D view.

4. Conclusions

Modern technology and new quality assurance constructs for treatment, along with state-of-the-art planning using patient-specific models has the potential to remove much of the uncertainty previously associated with RF hyperthermia and to enhance the outcome of combined treatment regimes.

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6. References

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