COMPARATIVE STUDY OF 2450 MHz and 915 MHz DIATHERMY APPLICATORS WITH PHANTOMS

[redacted]

In support of the BRH diathermy programs, techniques to evaluate the relative effectiveness and safety of applicators were developed. According to the proposed microwave diathermy standard, a leakage of not more than 10 mW/cm^2 at 5 cm from the phantom-applicator boundary is required. The leakage is determined under conditions in which a Specific Absorption Rate (SAR) of 235 W/kg is delivered to simulated muscle tissue of a phantom beneath its 1 cm or 2 cm fat layer. Three recently developed BRH applicators with chokes, one for 2450 MHz and two for 915 MHz use, meet the requirements of the proposed standard (the smaller 915 MHz applicator has a thin sheet of absorbing material around the exterior choke surface). Analysis of their performance revealed that it is much easier to control leakage at 2450 MHz than at 915 MHz. The 2450 MHz applicator has less than 5 mW/cm^2 leakage for both direct contact and 1 cm spacing between aperture and planar phantom. Both the large and small 915 MHz applicators have less than 5 mW/cm^2 leakage for direct contact. However, for a 1cm spacing between aperture and planar phantom, the leakage exceeds 10 mW/cm^2 for the large 915 MHz applicator and is about 100 mW/cm^2 for the small 915 MHz applicator.

Four microwave hyperthermia applicators of various cancer therapy groups, including RTOG, were evaluated. None of these applicators had special design features to control leakage radiation. They include a 2450 MHz design with three concentric circular tubes and three 915 MHz designs with dielectrically loaded waveguides. A comparison of the heating patterns of all the tested applicators shows that the depth of penetration normal to the fat-muscle interface (defined at a point where half the maximum SAR in muscle tissue exists) is nearly identical for 2450 MHz and 915 MHz. The depth is about 2 cm beneath the fat-muscle interface for both of these ISM frequencies.

To summarize, 915 MHz applicators require much more net power than 2450 MHz applicators to deliver the same SAR to muscle tissue, when not in direct contact. For even a small spacing between aperture and phantom (cm), excessive leakage results. In addition, since depth of penetration is about the same, 2450 MHz applicators seem to be considerably more effective and safe.

Summary - In support of the BRH diathermy programs, techniques to evaluate the relative effectiveness and safety of applicators were developed. (1,2) According to the proposed microwave diathermy standard, a leakage of not more than 10mW/cm^2 at 5 cm from the phantom-applicator boundary is required. The leakage is determined under conditions in which a Specific Absorption Rate (SAR) of 235 W/kg is delivered to simulated muscle tissue of a phantom beneath its 1 cm or 2 cm fat layer. Three recently developed BRH applicators and four microwave hyperthermia applicators developed by various cancer groups, including members of the Radiation Therapy Oncology Group (ROTG), were evaluated. The BRH applicators have chokes to control leakage; however, none of the other designs have special features to limit unwanted leakage radiation.

The BRH applicators have the following features: One of the new designs operates at 2450 MHz and is a circularly polarized horn with a microwave choke around a 15 cm diameter aperture. The other two, which operate at 915 MHz, are designed with four ridges inside a circular waveguide to provide circular polarization. The larger of the 915 MHz applicators has a 25 cm diameter aperture with three concentric annular choke and a thin sheet of absorbing material around its exterior surface.

The hyperthermia applicators are as follows: One of the microwave hyperthermia designs operate at 2450 MHz and the other three at 915 MHz. The 2450 circular applicator consists of three concentric cylindrical tubes. (3) All the 915 MHz units are basically dielectrically loaded waveguide structures. One is a loaded WR-340 applicator in which a TE_{10} mode is excited; it has a cross section of 8.6 by 4.8 cm. The second is an aircooled cavity applicator with a square section of 13cm by 13cm. (4) The third applicator uses an 8 cm square waveguide cross section to excite both the TE_{10} and TE_{01} modes.

All of the above applicators were thermographically analyzed using planar phantoms, described previously. The BRH 2450 MHz applicator has less than 5 mW/cm^2 leakage for both direct contact and 1 cm spacing between the aperture and planar phantom. The net power required to deliver 235 W/kg is 19 watts for the 1 cm fat layer and 57 watts for the 2 cm layer when in direct contact. At 1 cm above the phantom, the corresponding required net power values are 31 watts and 64 watts to deliver 235 W/kg. The width 'w'of the heating pattern (at a point where the SAR is half the maximum SAR) is 7.6 cm. A depth of penetration 'd' (normal to the fat-muscle interface in the phantom, defined at a point where the SAR is half the maximum) is 2.2 cm for the lcm fat layer. The values for w and d are 7.2 cm and 2 cm respectively for the 2 cm layer. For lcm spacing, the widths are somewhat larger, but d is 2 cm for both fat thicknesses. The required net power for 235 W/kg power deposition for the circular 2450 MHz applicator is 26 watts when a 1 cm fat layer phantom is heated. The resulting leakage is less than 4 mW/cm^2, w is equal to 4 cm and d is equal to 2.2 cm.

Both the large and small 915 MHz applicators have less than 5 mW/cm^2 leakage when in direct contact with the planar phantom. The net power required for the 235 W/kg power deposition by the small applicator is 33 watts for the 1 cm layer and 85 watts for the 2 cm layer. The corresponding values for the large applicator are 36 watts and 72 watts respectively. The w values of the approximately rectangular heating pattern are for the small applicator, using 1 cm fat layer, 4.2 cm and 6.6 cm and somewhat larger for the 2 cm fat layer. The d values for both cases are 2 cm. At 1 cm spacing, the required net power increases considerably with resulting high leakage. The smaller applicator power requirements are bigger. For the small applicator, for example, the values are about 350 watts with a leakage of about 130 mW/cm^2 for the 2 cm layer. For the large applicator, the values are considerably less with the leakage about 17 mW/cm^2. For the WR-340 applicator, the net power values are 94 watts and 216 watts when the applicator is in direct contact with the 1 cm and 2 cm layer of the planar phantom. The corresponding leakage values are 27.2 mW/cm^2 and 54.8 mW/cm^2 and about double for a 1 cm spacing between applicator and phantom surface. For both fat thicknesses, the depth of penetration is about 2 cm and the widths about the same (5.4 cm and 5.6 cm).

For the cavity applicator in direct contact with the planar phantom, the required net power is 98 watts with a leakage of 15 mW/cm^2 for 1 cm fat thickness and 58 watts with a leakage of 20 mW/cm^2 for the 2 cm. At 1 cm spacing, the corresponding power levels are 193 watts with 85 mW/cm^2 for the 1cm fat layer and 160 watts with 60 mW/cm^2 for the 2 cm fat layer. For the direct contact case, the w values for the approximately rectangular heating pattern are 3.3 cm and 2.7 cm for the 1 cm fat layer and about the same for the other layer; d is about 2 cm for the two layers. The square waveguide applicator has a w of 4.7 cm for its symmetrical heating pattern of the TE_{10} and TE_{01} modal excitations. For the TE_{10} alone, the w dimensions of the unsymmetrical pattern are 6 cm and 3.8 cm. For the both cases, the depth is 2.2. cm.

To summarize (see table), 915 MHz applicators require much more power than 2450 MHz applicators to deliver the same SAR to muscle tissue when not in direct contact. For even small spacing between aperture and phantom (1 cm), excessive leakage results. In addition, since the depth of penetration is virtually the same for both frequencies, 2450 MHz applicators seem to be considerably more effective and safe.

References

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2. G. Kantor, D.M. Witters, A New 915 MHz Direct Contact Applicator, 1978 Symposium on Electromagnetic Fields in Biological Systems, Ottawa.
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Heating Patterns

Applicators	Frequency	Spacing (cm)	1cm layer w (cm)	1cm layer d (cm)	2cm layer w (cm)	2cm layer d (cm)
BRH	2450	0	7.6	2.2	7.2	2.0
		1	9.3	2.0	7.5	2.0
Circular	2450	0	4.0	2.2		
BRH(small)	915	0	4.2&6.6	2.0&2.0	5.9&7.4	2.0&2.0
		1	7.2&7.5	1.7&2.3	9.3&6.3	0.9&1.1
BRH(large)	915	0	6.0&8.3	1.7&2.2	7.4&8.0	2.0&2.2
		1	7.8&9.0	2.0&2.0	8.4&8.7	2.1&2.0
WR-340	915	0	5.4	2.0	5.6	2.1
Cavity	915	0	3.4&2.7	2.0&2.0	3.3&2.5	2.0&2.2
		1	3.3	2.0	3.2	2.0

Effectiveness and Safety

Applicator	Frequency (MHz)	Spacing (cm)	1cm layer Net Power (watts)	1cm layer Leakage (mW/cm^2)	2cm layer Net Power (watts)	2cm layer Leakage (mW/cm^2)
BRH	2450	0	19	0.2	57	0.4
		1	31	3.1	64	2.3
Circular	2450	0	26	4.0		
BRH(small)	915	0	33	2.5	85	3.7
		1	334	125	349	133
BRH(large)	915	0	36	0.2	72	0.5
		1	198	16.7	216	17.4
WR-340	915	0	94	27.2	216	54.8
Cavity	915	0	98	14.8	58	19.7
		1	193	85.0	160	61.0