THE EFFECT OF ANTENNA MATCH ON MICROWAVE RADIOMETRIC THERMAL PATTERNS

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Abstract

Microwave thermographic profiles of the breast region of healthy female volunteers were obtained using a 4.7 GHz radiometer. Apparent temperature elevations of about 0.4°C were seen in the areolar (nipple) region compared to the other areas of the breast. At least half of this apparent areolar temperature elevation may be attributed to improved antenna match at that site. The importance of antenna match in the proper evaluation of microwave thermographic studies is emphasized.

Introduction

The need for a reliable, noninvasive, and nonhazardous method for the detection of cancer, especially of the breast, has been well established. Thermographic techniques for cancer detection, based on elevated temperatures often found in malignancies, are noninvasive and nonhazardous, but of questionable accuracy compared to the more hazardous X-ray techniques.[1,2] One of the major limitations of infrared thermography is its poor penetration through biological tissues, resulting in the measurement of surface temperature. Thermography using microwaves, because of their superior penetration through tissues compared with infra-red, may provide more clinically-meaningful subsurface thermal information.

Our laboratory has begun to evaluate the cancer detection capabilities of a microwave thermography system which uses a 4.7 GHz radiometer.[3] Preliminary clinical results in patients with known malignancies appear encouraging.[4] Temperature differences (ΔT) consistent with biopsy-proved malignancies were obtained in four of six primary carcinomas of the breast, five of five patients with lymphoma, and ten of twelve women with recurrent breast cancer. Negative results were obtained mainly in patients with more deeply-seated tumors.

A firm knowledge of the thermal profiles in healthy individuals is necessary for interpreting results obtained in cancer patients. Preliminary results[5] indicating the reproducibility of thermal measurements using various heated and unheated antennae have been reported earlier. Additionally, since the microwave radiometer reading depends on both tissue temperature and the degree of mismatch between the antenna and tissue, knowledge of the variation in antenna match as a function of anatomic site in various healthy and malignant tissues is needed.

Receiver Antennae

The radiometer, or receiver, antennae as shown in Figure 1 are reasonably well matched over the frequency range of the radiometer. The return loss is normally better than 10 dB when held against the hand. Return loss of 10 dB corresponds to a transmission loss of 0.45 dB, or 90% power transmitted. The insertion loss of the antenna was obtained by measuring the total loss of two identical antennae in series; i.e., mated at the waveguide openings. Assuming the transitions to be equal in loss, it was determined that the insertion loss of the single antenna was approximately 0.3 dB. To reduce the physical size of the normal C-band waveguide, dielectric loading is employed. The dielectric used is aluminum oxide having a relative dielectric constant, ϵ_r, of 9.5. The aperture measures 1.58cm x 0.79cm. The cut-off characteristics of the C-band waveguide are utilized, the waveguide forming the high pass filter to isolate the high power low frequency transmitter (when used in conjunction with hyperthermia equipment).

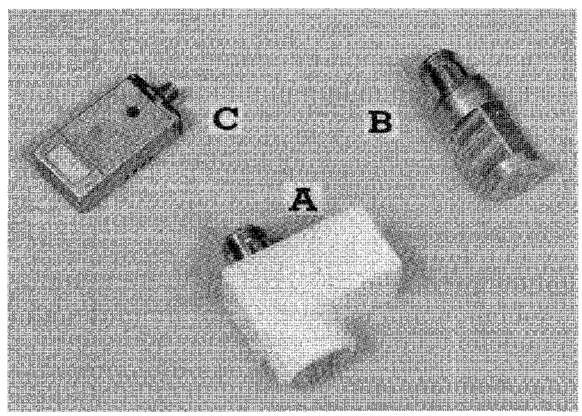

Figure 1 - Receiver Antennae

The basic radiometer antenna is shown in Figure 1B. The heated version of the radiometer antenna is shown in Figure 1A. A heater and proportional thermostat are provided in the antenna to maintain a constant temperature at or very near to that of the surface temperature of the human body. The advantages of thermal matching of the antenna have been reported. [6]

A new "compensated" low profile antenna has been developed having an improved match (i.e., less dependent upon anatomic site) with respect to the normal heated antenna. The unheated configuration of this compensated antenna is shown in Figure 1C, the major difference being the addition of a 90° E-plane bend to allow the antenna to lie flat against the body surface. The 90° E-plane bend is accomplished in aluminum oxide to maintain the same aperture size.

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Microwave Thermal Profiles

Sixty-one microwave thermal profiles at 40 defined anatomic locations were obtained from 24 healthy female volunteers aged 22-67. The anatomic locations illustrated in Figure 2 include the forearm (reference temperature), the forehead, the areolae, the quadrants of each breast, six positions on the right (RIM) and left (LIM) internal mammary lymph node chains, four positions on the right (RN) and left (LN) sternocleidomastoid lymphatic chains. The antenna (Figure 1A) was heated to 34.6 ± 0.1^{o}C to match the subject's temperature, minimizing thermal drift between subject and antenna. The antenna was placed for 30-60 seconds in direct contact with each of the 40 sites. Results are summarized in Table I. Using the right forearm as the reference temperature, temperature differences between the right forearm and the remaining 39 sites are listed as the mean ± SEM for all 24 volunteers and for the age groups as shown in Table I.

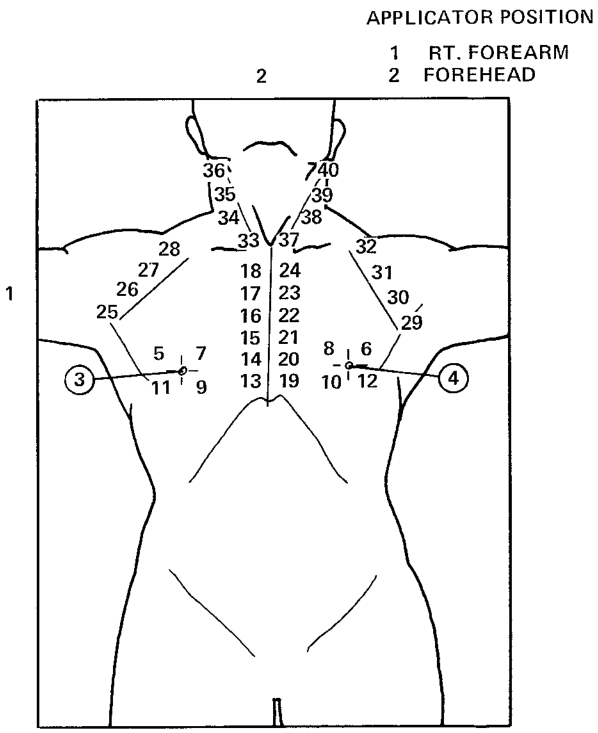

FIGURE 2

STANDARD 40 POSITION EXAMINATION

Position Number	Anatomic Location	All Women N = 61	Age 20-29 N = 39	Age 30-39 N = 14	Age 40-49 N = 7	Age 60-69 N = 1
1	Rt. Forearm	0	0	0	0	0
2	Forehead	0.69 ± 0.04	0.70 ± 0.05	0.65 ± 0.07	0.76 ± 0.09	0.49
3	Rt. Areola	0.33 ± 0.05	0.37 ± 0.05	0.30 ± 0.11	0.21 ± 0.22	0.03
4	Lt. Areola	0.26 ± 0.05	0.33 ± 0.06	0.14 ± 0.13	0.18 ± 0.25	-0.30
5	RUO Quadrant	-0.05 ± 0.04	0.03 ± 0.04	-0.12 ± 0.07	-0.23 ± 0.12	-0.69
6	LUO Quadrant	-0.14 ± 0.05	-0.04 ± 0.05	-0.31 ± 0.12	-0.30 ± 0.12	-0.88
7	RUI Quadrant	-0.03 ± 0.05	-0.02 ± 0.04	-0.05 ± 0.05	-0.03 ± 0.12	-0.39
8	LUI Quadrant	-0.07 ± 0.04	-0.01 ± 0.04	-0.11 ± 0.11	-0.18 ± 0.14	-0.58
9	RLI Quadrant	-0.04 ± 0.04	-0.05 ± 0.04	0.05 ± 0.09	-0.14 ± 0.16	-0.41
10	LLI Quadrant	-0.04 ± 0.03	0.00 ± 0.04	-0.02 ± 0.07	-0.26 ± 0.13	-0.40
11	RLO Quadrant	-0.02 ± 0.04	0.01 ± 0.05	-0.03 ± 0.05	-0.14 ± 0.17	-0.53
12	LLO Quadrant	-0.01 ± 0.03	0.02 ± 0.03	-0.06 ± 0.08	-0.03 ± 0.06	-0.51
13	RIM - 1	0.07 ± 0.03	0.09 ± 0.04	0.01 ± 0.06	0.11 ± 0.12	0.05
14	RIM - 2	0.07 ± 0.03	0.10 ± 0.03	0.03 ± 0.07	0.07 ± 0.10	-0.25
15	RIM - 3	0.08 ± 0.03	0.11 ± 0.03	0.02 ± 0.05	0.11 ± 0.09	-0.28
16	RIM - 4	0.07 ± 0.03	0.08 ± 0.04	0.00 ± 0.06	0.16 ± 0.13	-0.19
17	RIM - 5	0.10 ± 0.04	0.13 ± 0.04	0.05 ± 0.07	0.15 ± 0.11	-0.39
18	RIM - 6	0.19 ± 0.03	0.25 ± 0.04	0.10 ± 0.06	0.07 ± 0.09	-0.24
19	LIM - 1	0.10 ± 0.03	0.13 ± 0.03	0.02 ± 0.06	0.05 ± 0.11	0.03
20	LIM - 2	0.15 ± 0.04	0.21 ± 0.04	0.07 ± 0.06	0.03 ± 0.12	-0.05
21	LIM - 3	0.16 ± 0.04	0.19 ± 0.05	0.09 ± 0.06	0.18 ± 0.11	-0.19
22	LIM - 4	0.11 ± 0.04	0.16 ± 0.05	-0.05 ± 0.06	0.25 ± 0.14	-0.33
23	LIM - 5	0.09 ± 0.04	0.11 ± 0.04	0.07 ± 0.09	0.04 ± 0.11	-0.29
24	LIM - 6	0.16 ± 0.04	0.25 ± 0.04	0.06 ± 0.06	-0.05 ± 0.10	-0.35
25	RAX - 1	-0.04 ± 0.03	-0.03 ± 0.03	0.05 ± 0.09	-0.17 ± 0.12	-0.34
26	RAX - 2	0.05 ± 0.04	0.03 ± 0.04	0.03 ± 0.10	0.14 ± 0.11	0.51
27	RAX - 3	0.11 ± 0.04	0.10 ± 0.04	0.09 ± 0.11	0.21 ± 0.14	0.29
28	RAX - 4	0.15 ± 0.04	0.21 ± 0.05	0.09 ± 0.09	0.02 ± 0.12	-0.43
29	LAX - 1	0.10 ± 0.03	-0.10 ± 0.03	-0.06 ± 0.10	-0.13 ± 0.10	-0.45
30	LAX - 2	-0.06 ± 0.04	-0.05 ± 0.04	-0.10 ± 0.11	0.09 ± 0.09	-0.25
31	LAX - 3	0.02 ± 0.04	0.07 ± 0.05	-0.08 ± 0.11	0.11 ± 0.08	-0.23
32	LAX - 4	0.10 ± 0.04	0.17 ± 0.05	0.01 ± 0.10	-0.04 ± 0.09	-0.35
33	RN - 1	0.74 ± 0.04	0.75 ± 0.06	0.67 ± 0.08	0.71 ± 0.12	0.38
34	RN - 2	0.77 ± 0.04	0.80 ± 0.05	0.78 ± 0.08	0.68 ± 0.09	0.43
35	RN - 3	0.72 ± 0.04	0.77 ± 0.05	0.67 ± 0.09	0.62 ± 0.11	0.39
36	RN - 4	0.70 ± 0.04	0.73 ± 0.06	0.62 ± 0.08	0.71 ± 0.10	0.39
37	LN - 1	0.68 ± 0.04	0.70 ± 0.05	0.63 ± 0.06	0.67 ± 0.10	0.30
38	LN - 2	0.75 ± 0.04	0.80 ± 0.05	0.69 ± 0.07	0.65 ± 0.11	0.43
39	LN - 3	0.76 ± 0.04	0.81 ± 0.05	0.71 ± 0.07	0.63 ± 0.12	0.39
40	LN - 4	0.70 ± 0.04	0.75 ± 0.06	0.65 ± 0.07	0.62 ± 0.08	0.20

TABLE I

MICROWAVE RADIOMETRIC THERMAL PROFILES IN HEALTHY FEMALE VOLUNTEERS

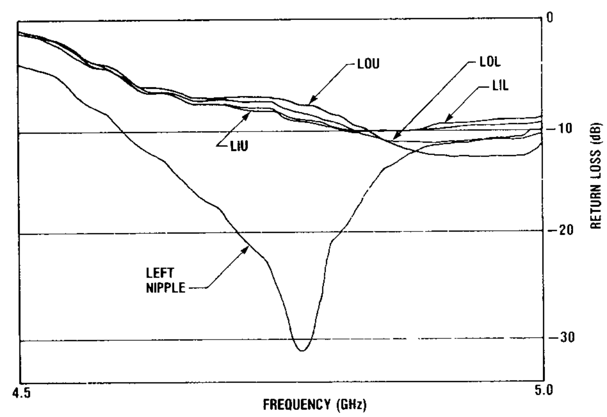

FIGURE 3

HEATED ANTENNA (34.1°C) (UNCOMPENSATED) RETURN LOSS VS. FREQUENCY HUMAN VOLUNTEER CH5181-29 LEFT BREAST

Antenna Match Studies

Since the apparent thermal differences shown in Table I can be attributed to true temperature differences and/or differences in antenna match at different anatomic sites, a second study was conducted to measure antenna match at different anatomic sites. Measurements of return loss over the radiometer bandwidth of 4.5 to 5.0 GHz were made in female volunteers aged 23-66 using the antennae shown as Figures 1A and 1C. (Antenna 1A was maintained at 34.1^{o}C.) Typical VSWR measurements are shown as Figure 3 for Antenna 1A and Figure 4 for Antenna 1C.

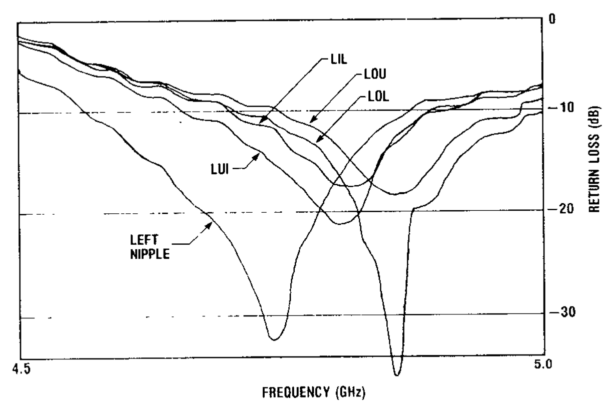

FIGURE 4

LOW PROFILE ANTENNA (COMPENSATED) RETURN LOSS VS. FREQUENCY HUMAN VOLUNTEER CH-5181-29 LEFT BREAST

Figure 5 represents the radiometer measurement utilizing the uncompensated antenna (i.e., Antenna 1A). Note the temperature differential between the areola and the surrounding tissue of the left breast is 0.4°C. Figure 6 represents a radiometer measurement on the same breast utilizing the compensated antenna (i.e., Antenna 1C). The measured thermal difference is now reduced to 0.13°C. It should be further noted that the bilateral temperature differential (Figure 5) between either areola and the surrounding tissue is approximately equal. The magnitude of the difference is in part attributed to the antenna match.

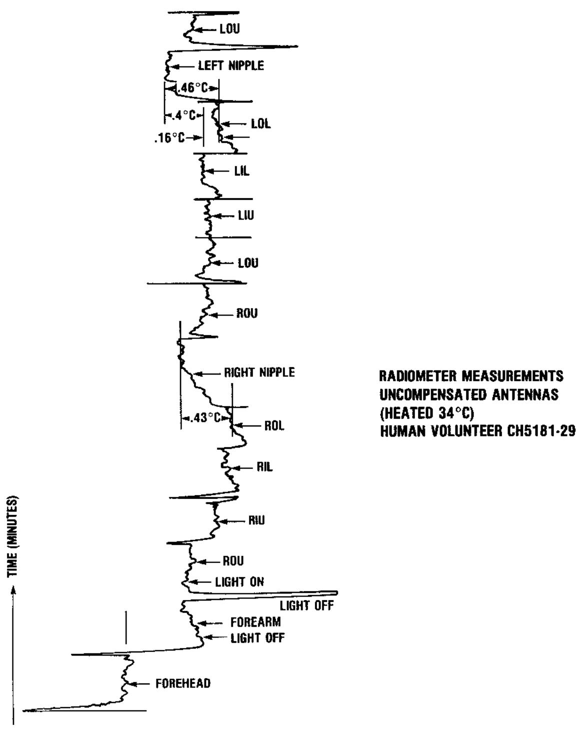

Figure 5

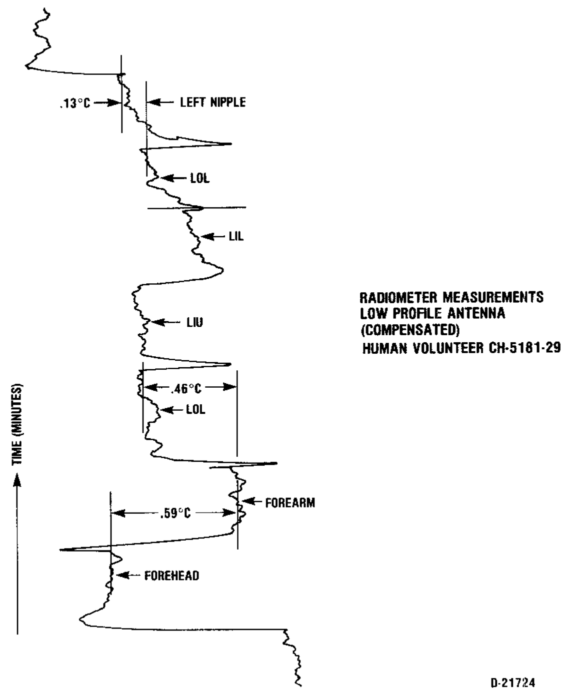

Figure 6

Conclusions

The apparent higher temperature commonly associated with the areolar area with respect to the other quadrants of the breast are partially attributed to the improved match of the antenna over the entire bandwidth of the radiometer at that site. The eventual use of multiple antennae will allow optimization of the individual antenna elements to a specific anatomic site. The use of the multiple antennae or array of tightly-grouped sensors arrayed in a conformal manner is analogous to phased arrays now widely used in radar, providing greater resolution and sensitivity.

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