From Outer to Inner Space

Bruce Rosen

THE ASTROPHYSICAL JOURNAL, 222:132–139, 1978 May 15

OBSERVATIONS OF OH AND H_2O MICROWAVE MASER EMISSION FROM VY CANIS MAJORIS

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ABSTRACT

VLBI observations of the H_2O emission from VY CMa made in 1974 and 1976 show the diameter of the masing region to be about 5×10^{15} cm, and the diameters of the individual components to be about 5×10^{13} cm. The total mass of the gas in the water masing region is estimated to be $10^{-1}\ M_\odot$, and the density is about $10^9\ \mathrm{cm}^{-3}$. The H_2O and main-line OH maser spectra from single antenna measurements show substantial changes within a few months. These changes may be correlated with changes in the optical spectrum. Expanding-shell models, with emission from both the limbs and the direction along the line of sight to the star, can explain the observations.

Subject headings: infrared: sources — interferometry — masers — stars: circumstellar shells — stars: individual — stars: mass loss

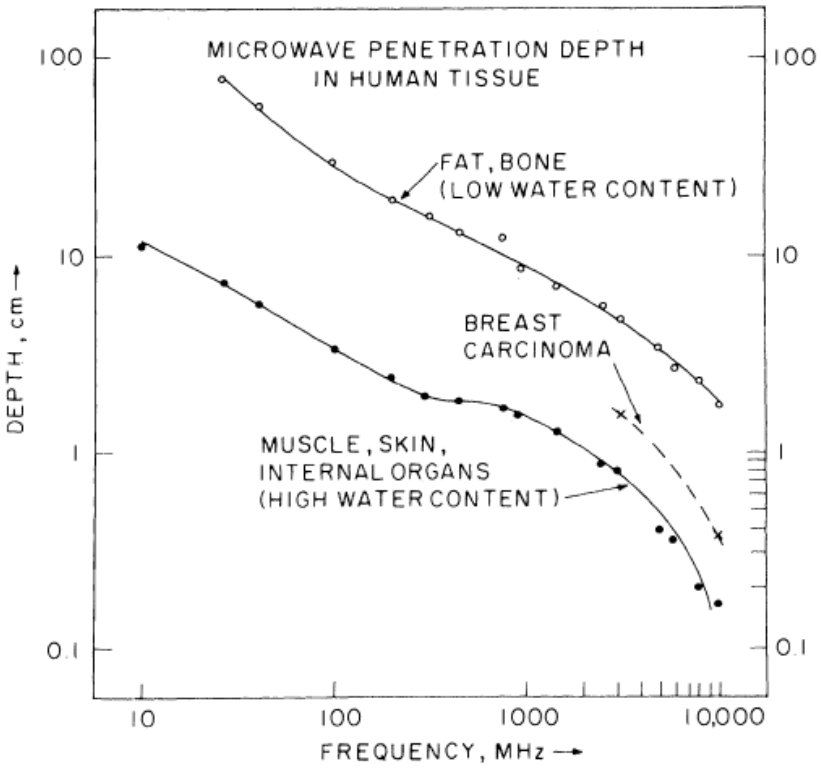
Reports

Alan H. Barrett and Philip C. Myers Science,
Vol. 190, No. 4215 (Nov. 14, 1975),
pp. 669-671

Subcutaneous Temperatures: A Method of Noninvasive Sensing

Abstract. *A new method of noninvasive sensing of the subsurface temperature distribution in human and animal tissue is described. Thermal radiation emitted from subsurface depths of several centimeters can be detected with microwave receivers. Temperature sensitivity of order 0.1°C and spatial resolution of approximately 1 by 2 centimeters have been obtained. Measurements demonstrating the technique, with feline and human tissue, are reported. A potential medical application is the detection of subsurface thermal anomalies such as malignant tumors and regions of vascular insufficiency.*

Microwave Penetration Depth



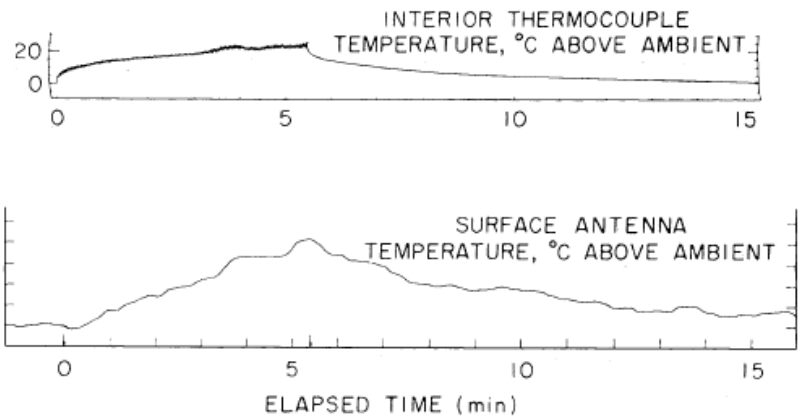


Fig. 1 (left). Penetration depth as a function of frequency for typical human tissues. The greatest penetration is provided by low frequencies but the spatial resolution is worsened. The frequency of operation of typical infrared thermographs is 10^7 to 10^8 Mhz for which there is virtually no penetration (1000 Mhz = 1 Ghz). Fig. 2 (right). Time history of (top curve) temperature of dead cat thigh muscle, heated with pulsed focused ultrasound, measured with a thermocouple implanted at the focus approximately 1.5 cm beneath the skin surface, and (bottom curve) temperature recorded by 3-Ghz microwave radiometer, with antenna fixed against skin surface. Arrows indicate start and end of ultrasonic irradiation period.

There are many potential medical applications of microwave radiometry. By analogy with infrared thermography, we may expect these to include detection of sub-surface thermal anomalies such as malignant tumors, especially in the female breast; localized inflammations, such as appendicitis; and vascular insufficiency in the limbs and in the brain. However, the usefulness of the technique is difficult to predict because detailed knowledge of the internal thermal structure of the human body is sparse. Extensive clinical evaluation, involving observations at more than one frequency, will be required. If simultaneous observations are made at two well-separated frequencies, the ability to determine the depth of a particular thermal anomaly will be improved. However, this depth resolution will still be crude, of order 1 cm at best, because of the long wavelengths involved. Experiments at other frequencies have been performed by others in the laboratory but have not been the subject of detailed clinical evaluation (8). Infrared thermography has been utilized in the detection of breast cancer for many years, and this is an area where microwave thermography is being evaluated. Micro-wave thermograms at 3.3 Ghz on some 30 to 40 female patients per week at Faulkner Hospital, Boston, are being correlated with mammography, infrared thermography, clinical, and, where appropriate, biopsy results. These data are the first microwave thermographic data taken in a systematic, routine manner in a clinical environment and should help establish the currently un-known microwave emission patterns from the breasts of normal patients. Once these patterns are known with confidence, an examination of departures can be carried out for diagnostic purposes. Our initial data indicate good agreement with infrared patterns, but insufficient data exist for any further conclusions.

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MICROWAVE THERMOGRAPHY FOR THE DETECTION OF BREAST CANCER: A DISCUSSION AND EVALUATION OF A 6 GHZ SYSTEM

by

BRUCE ROBERT ROSEN

Submitted to the Department of Physics
January, 1980 in partial fulfillment of the
requirements for the Degree of Master of Science
in Physics

Abstract

This thesis presents a general discussion of a 6 GHz Microwave Thermograph used for the detection of breast cancer. An evaluation of the antenna power pattern was done, and showed that , first, almost all the energy received at 6 GHz has its origin within the 3 mm skin layer overlying the breast, and second, that resolution is likely to be limited more by examination time than by the intrinsic power pattern of the antenna.

Using the results of 960 patients measured with this device as part of a larger screen for breast cancer at Faulkner Hospital, 6 GHz thermography was found to be equivalent to both earlier L and S-band thermography as well as present Infra-red thermography, which showed a performance decrease over previous results. Combination with Infra-red thermography offered little improvements over 6 GHz thermography alone, leading to the conclusion that X-ray would remain an essential examination for all women if high sensitivity is to be retained.

Cost-benefit analysis was performed for both X-ray and clinical screening alone, and with microwave examination included as part of a two phase screen. X-ray screening was shown to reduce person-years lost to breast cancer by 47%, while two phase screening reduced years lost by 38% over those obtained without screening. The net costs of both forms of screening were high, mostly reflecting the cost of the actual screening program. Microwave examination did not improve the cost-effectiveness of mass screening for breast cancer.

Thesis Supervisor: Dr. Philip C. Myers
Title: Associate Professor of Physics

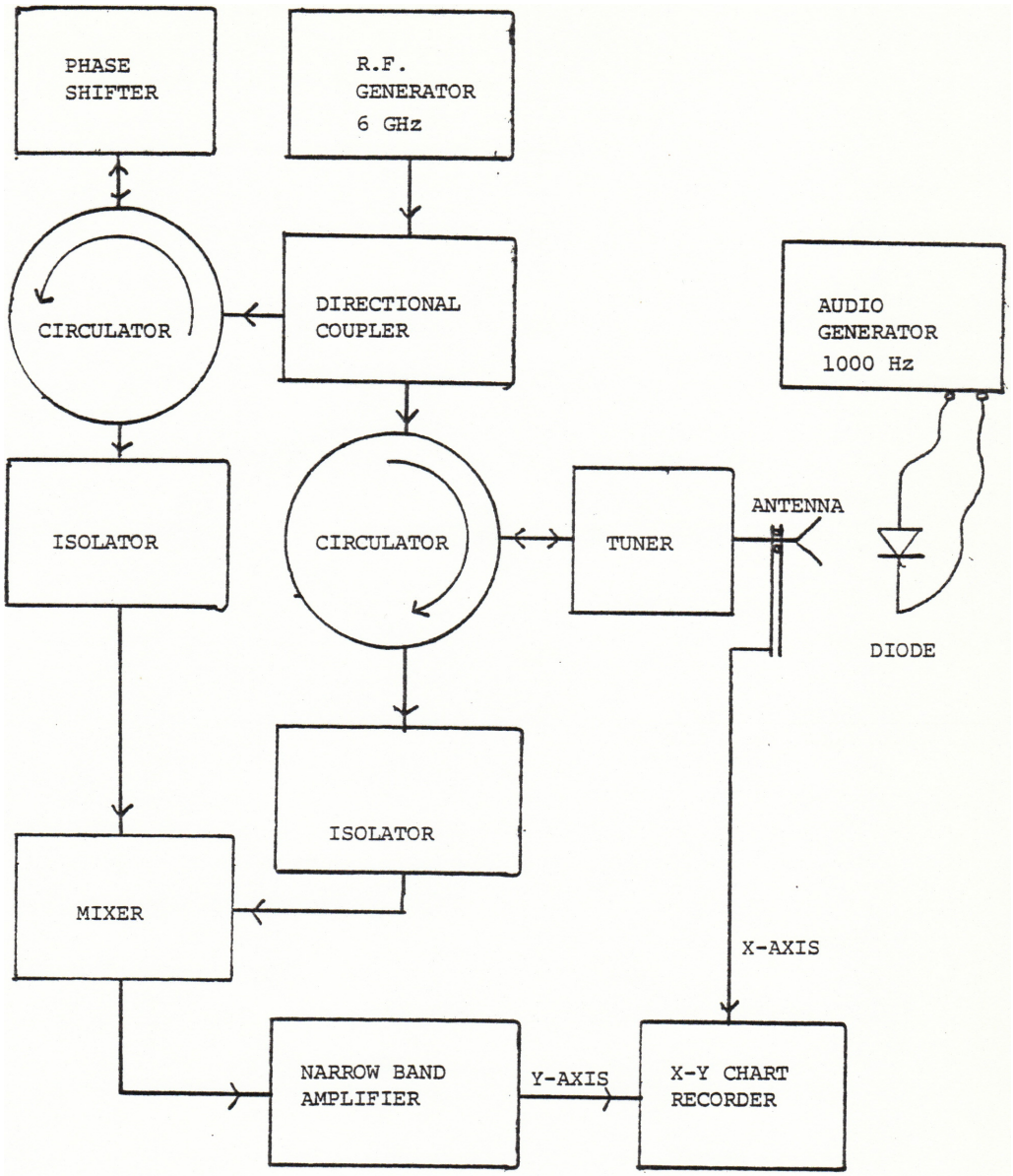


FIGURE 1. BLOCK DIAGRAM OF ANTENNA PATTERN MEASUREMENT SET-UP

Contour Map at 1.3cm

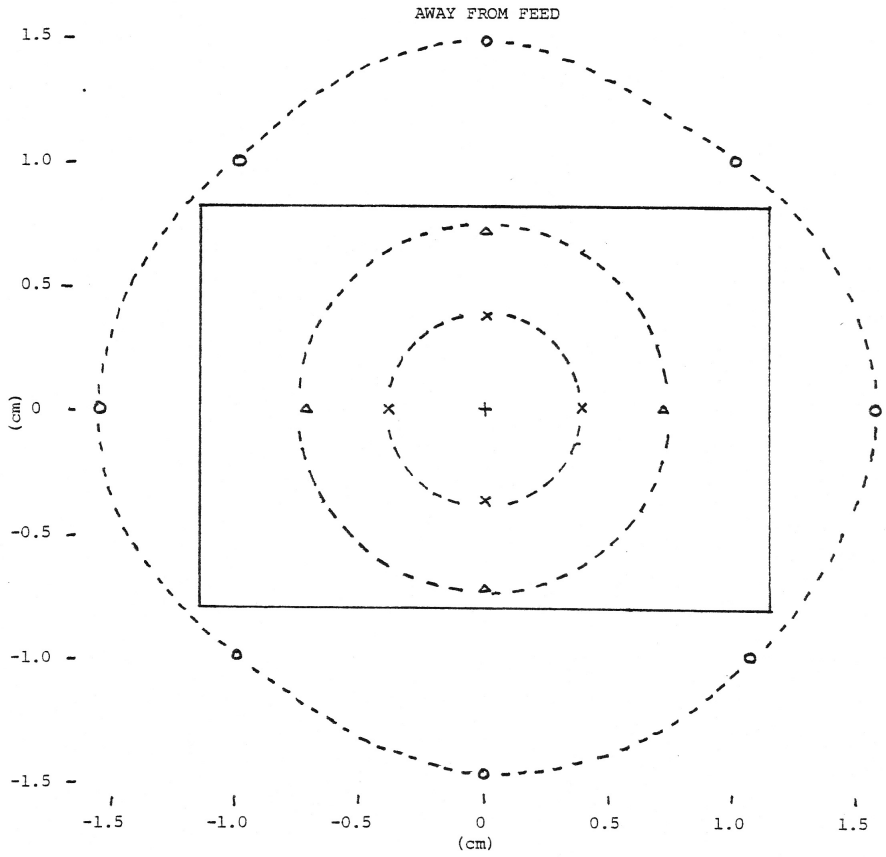


FIGURE 11. CONTOUR MAP - DEPTH EQUALS 1.3 CM

X = 1 db contour
▲ = 3 db contour
o = 10 db contour
+ = peak power point

Waveguide dimensions outlined

Histograms of Temperature Distributions: Cancer vs. Normal

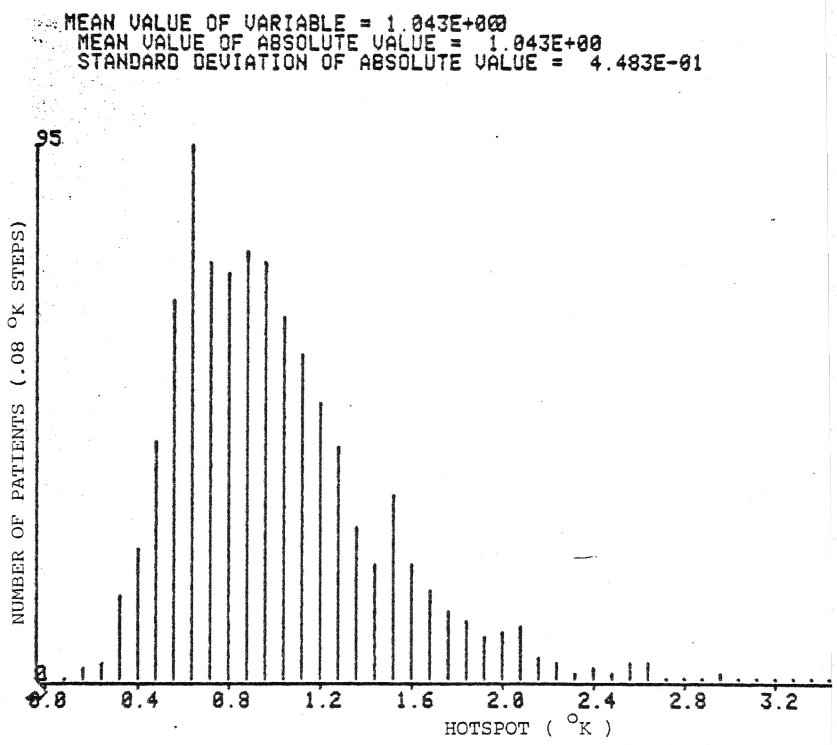


FIGURE 18. HISTOGRAM OF HOTSPOT (TEMPERATURE OF HOTTEST POINT M
AVERAGE TEMPERATURE, SAME BREAST) DISTRIBUTION FOR
NORMAL POPULATION.

Peak value labeled.

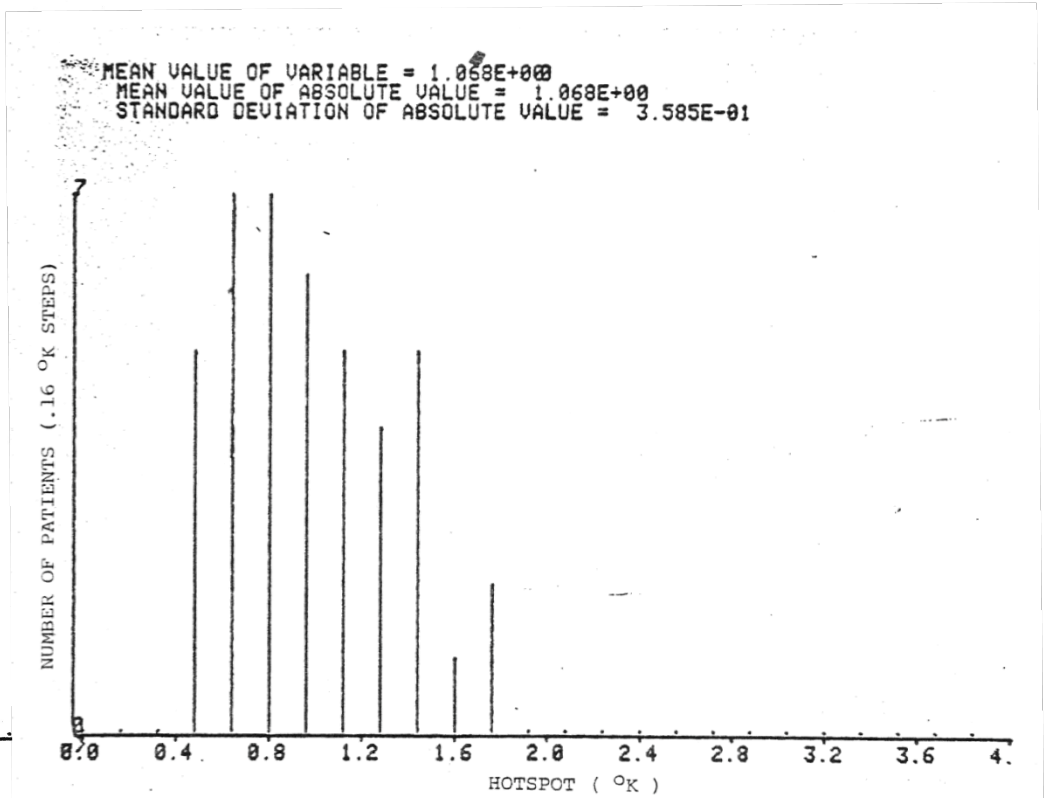


FIGURE 19. HISTOGRAM OF HOTSPOT DISTRIBUTION FOR CANCER PATIENTS.

Peak value labeled

Receiver Operator Curve (ROC)

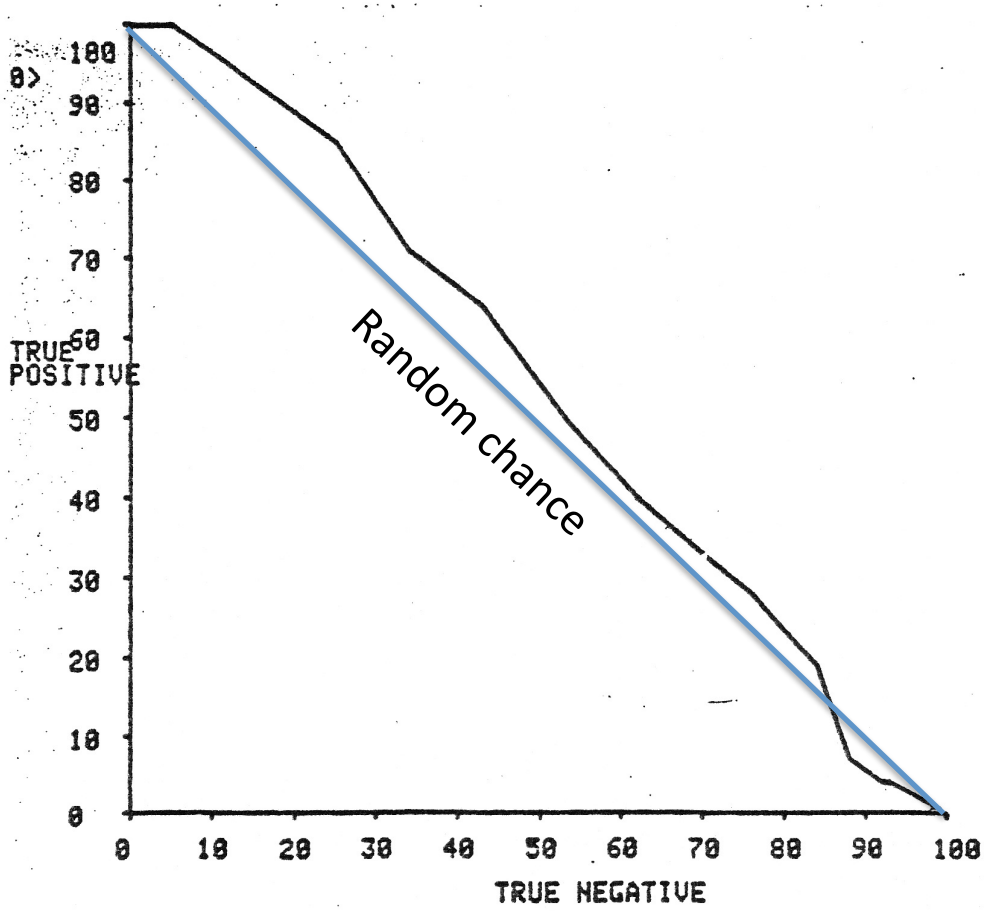


FIGURE 23. ROC CURVE USING HOTSPOT CRITERION.

Scatterplot: Cancer vs. Normal

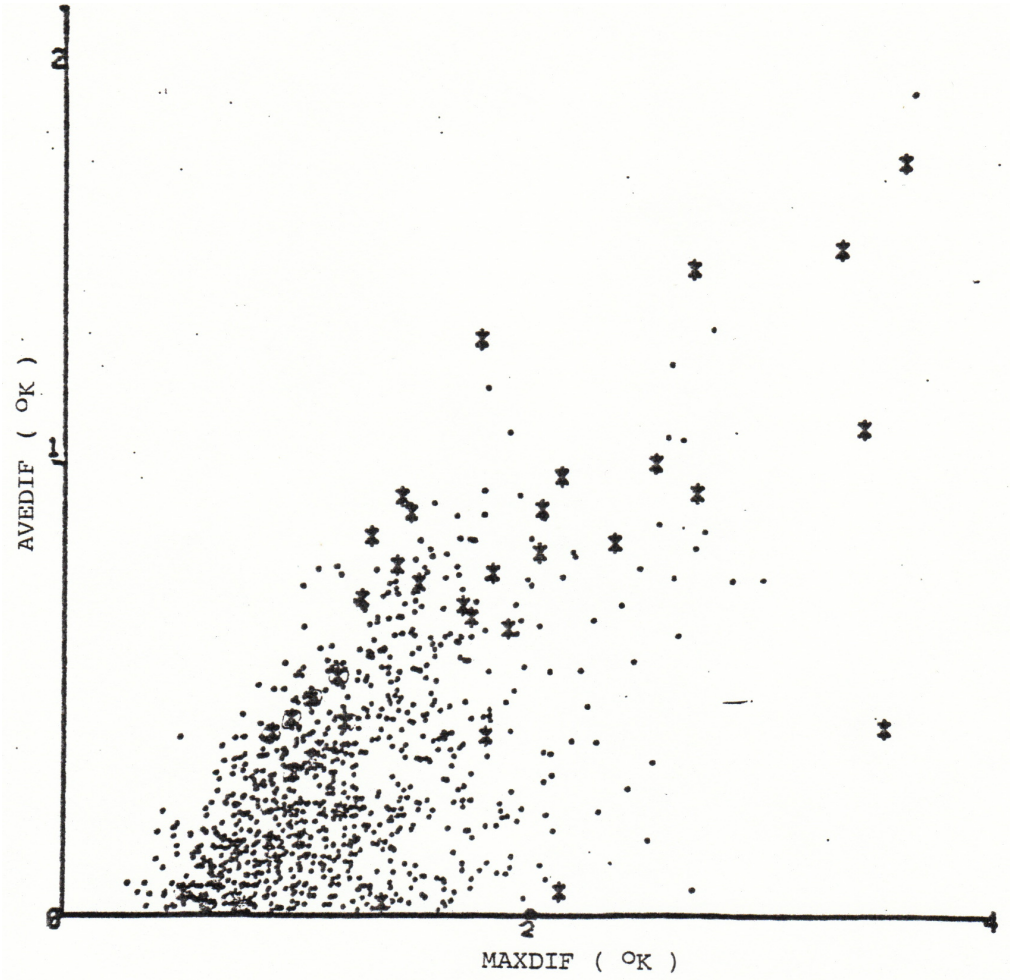


FIGURE 24 . AVEDIF VERSES MAXDIF.

* = Cancers
· = Normals

Corrected ROC Curves

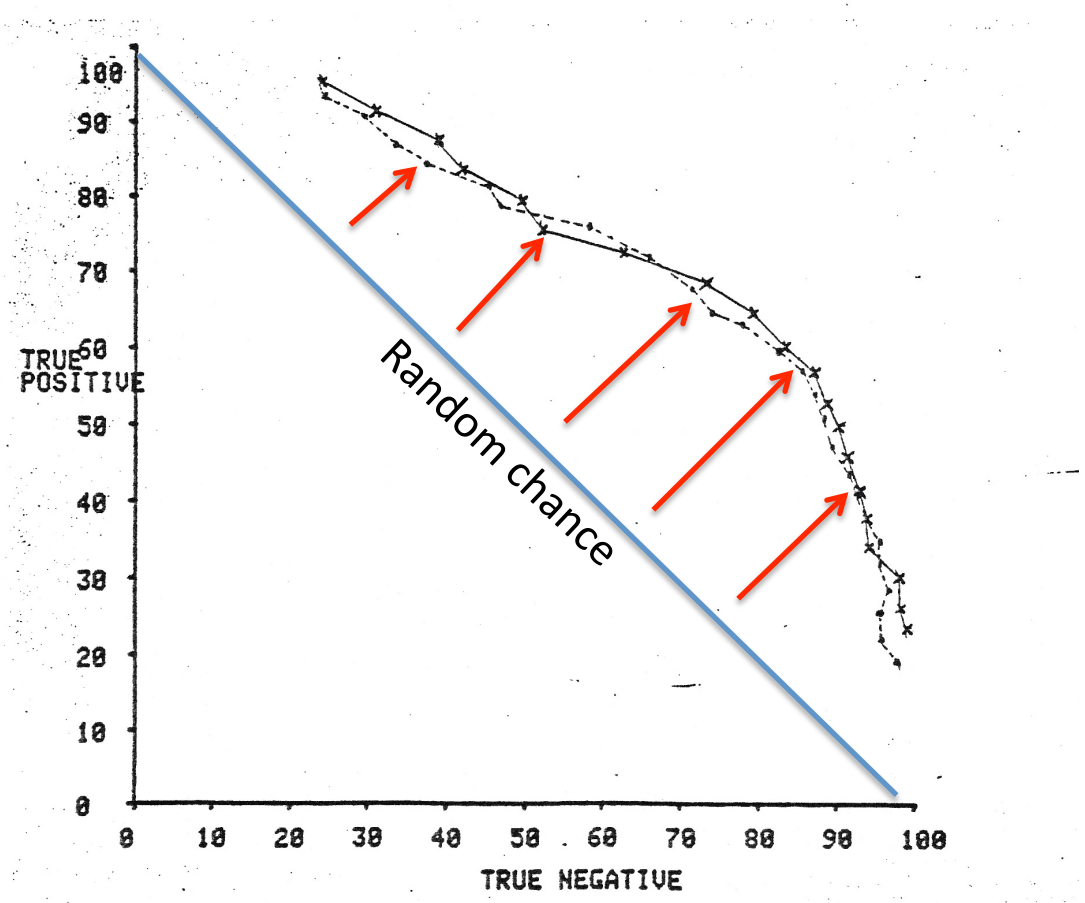


FIGURE 33. ROC CURVES FOR THE BEST OF BOTH RESULTS USING AVEDIF, MAXDIF, AND HOTSPOT, AND CORRECTED AVEDIF, MAXDIF, AND HOTSPOT.

x——x = Schwartz algorithms
·----· = Corrected algorithms.

A few Conclusions

A background in the nature of breast disease and currently available modalities to detect these motivated the rational behind microwave thermography. The basic principles of detecting subcutaneous temperature distributions was established. The analysis of the properties of the antenna used for the 6 GHz measurements showed that, first, almost all the energy measured at that frequency has its origin within the 3 mm skin layer, and, second, that ultimate resolution is likely to be limited more by examination time than by the intrinsic power pattern of the antenna, even for automated scanning devices.

Using the findings of 960 patient measurements the 6 GHz system was found to perform similarly to the 1.3 GHz thermograph as a stand-alone system for discriminating cancer from normals. New methods of processing the data allowed improved performance over earlier systems. When used in conjunction with the 6 GHz thermograph, IR data offered little improvement, demonstrating the similarity of the two methods. This in turn prevented thermographic methods from augmenting x-ray techniques in a satisfactory manner. Finally, using this result it was concluded that the present 6 GHz thermograph would not improve the performance of a large screening program for asymptomatic women, either by decreasing person-years lost to breast cancer or by improving cost-effectiveness of the screen.

Retrospective look at biopsy proven cancers

Infra-red results showed a significant improvement in TP of about 10 percentage points for both code 2 and code 3, with comparable TN. When analysed along with the microwave results, the important conclusion can be drawn that for those patients who were initally labeled cancer and turned out not to be, both forms of thermographic data did better than average in assigning their true state. This would indicate that the radiologists at Faulkner would be well advised to pay closer attention to thermographic results.

Measurement Positions

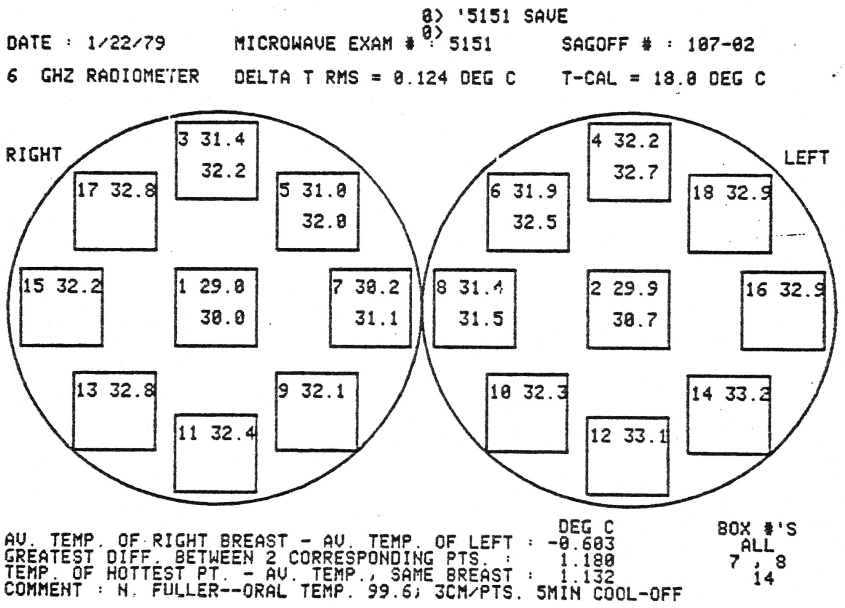
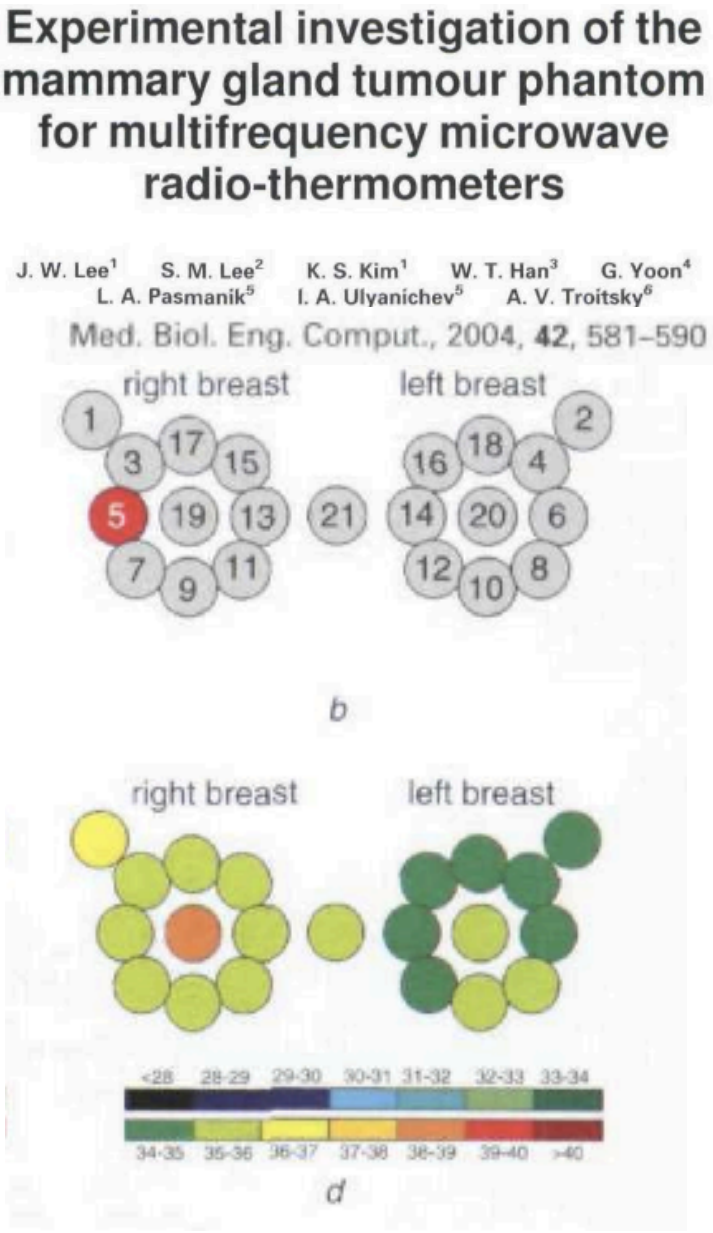


FIGURE 13. COMPUTER GENERATED GUIDE TO BREAST TEMPERATURE MEASUREMENT POSITIONS.

Measurement sequence labeled in the upper left corner of each box. Repeat measurements listed beneath initial reading. Statistics listed are computed without subtraction of a linear slope.



Microwave Radiometry: Its Importance to the Detection of Cancer

KENNETH L. CARR, FELLOW, IEEE

(*Invited Paper*)

Abstract—Developments in the application of microwave technology to the solution of medical problems, particularly the detection and treatment of cancer, have been very encouraging. In the treatment of cancer, for example, microwave hyperthermia has been accepted as an adjunctive procedure to radiation therapy in the treatment of superficial lesions. While not as widely reported, the use of microwave radiometry as a noninvasive, passive technique for the early detection of cancer appears very promising. Wider acceptance of these methods, however, awaits fundamental improvements in the ability to focus energy at depth in human tissue, an important and nontrivial antenna problem. Further development in the areas of antennas and antenna arrays is required if microwave technology is to provide a practical solution to the detection and treatment of cancer.

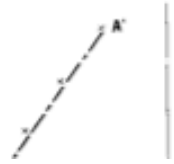
This paper discusses developments in the medical uses of microwave radiometry, particularly in relation to the early detection of cancer, as well as the significance of and progress in related antenna technology.

TABLE I
20 YEAR SURVIVAL RATE—BREAST CANCER*

SIZE AT TIME OF DETECTION	APPROXIMATE SURVIVAL RATE
3 CM DIA	50%
2	65%
1	80%
<< 1	95%

*Source: [2].

SCHEMATIC REPRESENTATION OF THE LIFE CYCLE OF A BREAST CANCER WITH A DOUBLING TIME OF 100 DAYS. THIS DEMONSTRATES THAT WHEN IT REACHED THE SIZE OF 0.2MM (WHICH MAY HAVE TAKEN 4 YEARS) THERE ARE STILL 4 YEARS TO GO BEFORE IT BECOMES A 1.0CM MASS. THE VISIBLE OR CLINICAL PHASE OF A BREAST CANCER MAY BE BUT A SHORT PERIOD IN ITS LIFE HISTORY.



Power Pattern 6GHz

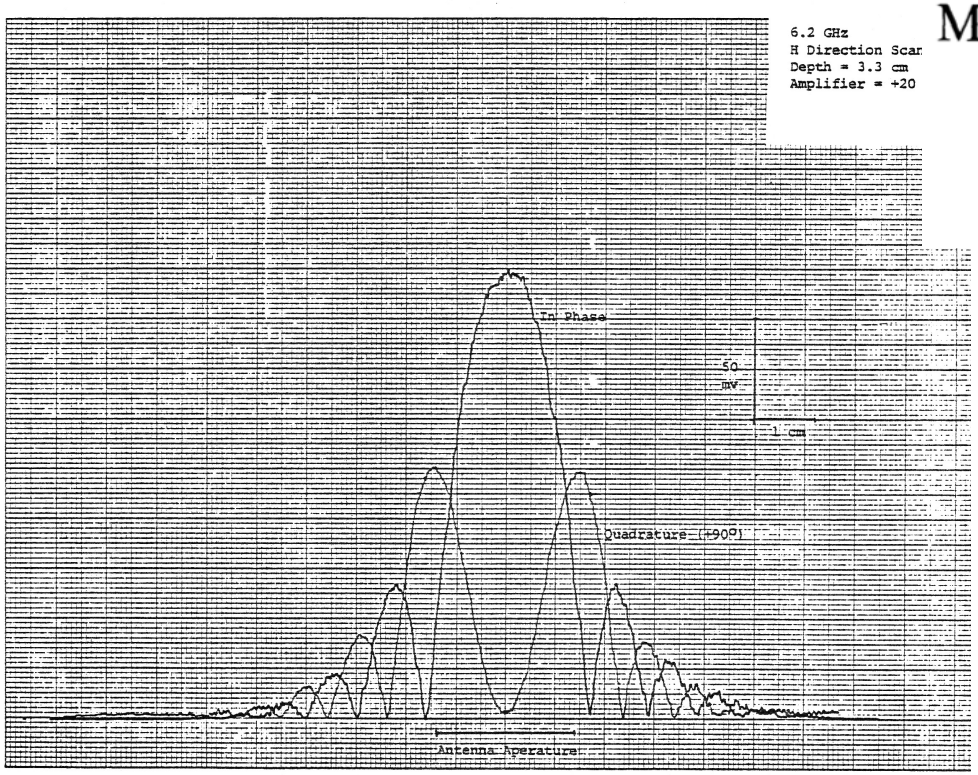


FIGURE 6. H DIRECTION POWER PATTERN SCAN : DEPTH = 3.3 cm , 6.2 GHz

IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 37, NO. 12, DECEMBER 1985

Microwave Radiometry: Its Importance to the Detection of Cancer

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(*Invited Paper*)

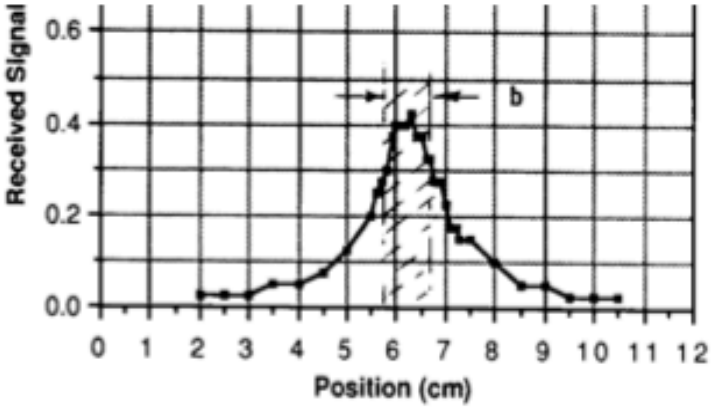

Fig. 8. Spatial resolution at 4.7 GHz using the dielectric-filled wave guide antenna.

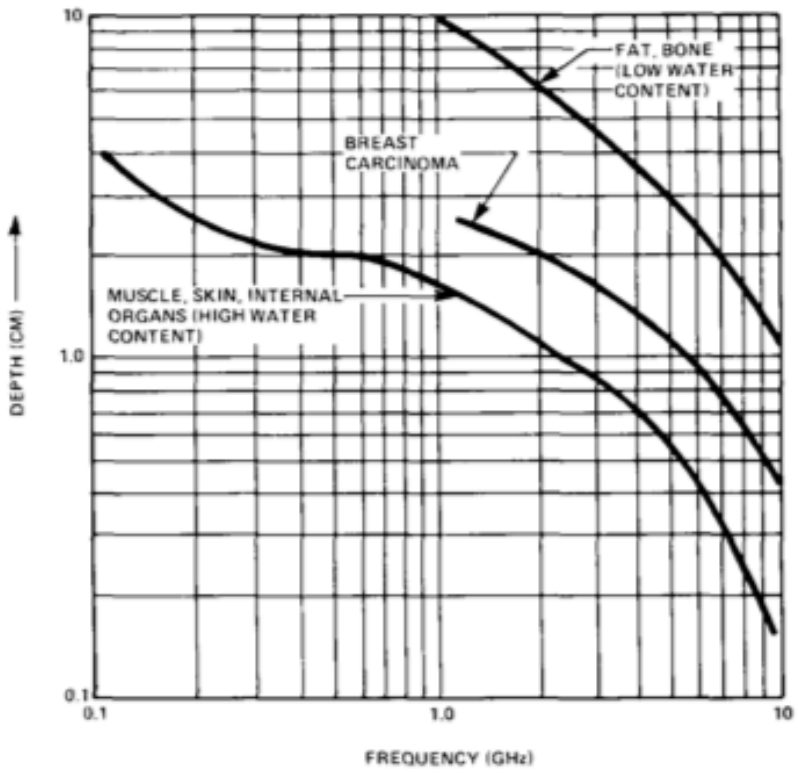

Fig. 4. Microwave penetration versus frequency (homogeneous media).

advantage of the corresponding higher levels of emission as evident in Fig. 2. The potential of detecting thermal anomalies, such as malignant tumors in the female breast using microwave radiometry, was recognized by researchers Barrett and Myers [15], [16], followed by others [17]–[21]. Improved transmission characteristics at the lower microwave frequencies tend to offset the corresponding lower level of emission. The dielectric properties of

ential between the antenna and the reference load. In the case where long integration times are involved, the long-term gain variations in the receiver must be considered. The long-term gain variations can degrade the minimum detectable temperature sensitivity (ΔT_s) in accordance with the following expression:

$$\Delta T_s = \Delta G/G(T_1 - T_2) \qquad \text{K rms} \qquad (1)$$

where ΔG is the receiver gain change, G is the nominal receiver gain, T_1 is the temperature of the reference load in kelvins, and T_2 is the temperature of the antenna in kelvins. Obviously, if T_1 approaches T_2 the effect on long-term receiver gain variations becomes negligible. It becomes advantageous, therefore, to maintain the temperature of the reference load approximately equal to the temperature of the unknown.

The radiometer design can be further modified to take into account antenna mismatch. If the receive antenna is noncontacting or remote, for example, the mismatch at the surface relative to the air can be significant, resulting in a dramatic reduction in surface emission. Ludeke and Kohler [28] have suggested the use of a radiation balancing radiometer employing noise injection, thus making the receiver temperature equal to the object temperature to eliminate the error due to reflectivity. However, if the radiometer is designed for a specific application, the use of site-optimized contact antennas could eliminate the need for this added complexity [29]. In this situation, however, thermal drift results from prolonged contact between a

V. Conclusion

The application of microwave technology to the solution of medical problems, specifically to the detection and treatment of cancer, has been very encouraging. It is generally agreed that hyperthermia (i.e., the application of microwave energy to elevate tumor temperature to cause cell necrosis) will play an increasingly important role in cancer therapy.

The use of microwave radiometry (i.e., a noninvasive, passive technique to allow the detection and diagnosis of pathologic conditions in which there are disease-related temperature differentials) is currently an experimental technique with studies being conducted by several teams around the world with limited yet encouraging results. Performance improvements and cost reduction in these areas will be assisted by the rapid progress in microwave devices, components, and signal processing techniques.

The antenna has become the critical component limiting system performance. The near-field region of a layered, absorptive, and inhomogeneous medium represents a difficult and challenging problem of electromagnetic theory. Further development in the areas of antennas and antenna arrays is required if microwave technology is to become an accepted and practical solution to the detection and treatment of cancer.

Microwave Radiometric Imaging at 3 GHz for the Exploration of Breast Tumors

B. BOCQUET, J. C. VAN DE VELDE, A. MAMOUNI,
Y. LEROY, G. GIAUX, J. DELANNOY,
AND D. DELVALEE

Abstract—**A process of microwave radiometric imaging working at 3 GHz permits the mapping of radiometric intensities on a square area about half a decimeter on a side. These data, translated in terms of colored image, point out the existence of lateral temperature gradients in the tissues. This system was initially used in order to examine large breast tumors; at present, it is also used for the detection of smaller, impalpable tumors. We try to define the rules for the characterization of benignity or malignancy of small tumors which appear in a mammographic examination (X rays). The definition of an appropriate parameter, deduced from this image processing, seems to make it possible to indicate if the tumor is benign or malignant.**

I. Introduction

For several years, because women are more aware of breast lumps, more breast tumors have been discovered at an early stage. Therefore, new problems arise for differential diagnosis. Indeed, these tumors are often so small that they cannot be investigated with clinical examination. Because some of these lumps cannot be characterized by mammography or percutaneous cytology, it is often necessary to resort to surgery, al-

Microwaves for breast cancer detection?

Elise C. Fear,
Paul M. Meaney
& Maria A. Stuchly

taking a look at a possibly safer way to check

From IIIE Potentials, 2003

Conclusions

Microwave systems for cancer detection are coming of age. Enough promise is there to be optimistic that in the next decade a viable system will become available. It is not expected that such a system or systems will replace x-ray mammography as a screening tool. But these systems used together can improve detection and limit false positive findings. Perhaps for young women for whom mammography is not recommended, a microwave system will become a useful and painless low risk diagnostic aid. At present, there is still a great deal of research and engineering design to be completed before this optimistic outlook becomes a reality.

Time-Depen
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Fernando Bardati, Gae

***Abstract*—Microwave radiometry h**
the noninvasive monitoring of internal t
bodies when the temperature is varie
external sources and contacting fluid. T
modeled as a discrete-time controlled stat
timate is cyclically updated exploiting rad
The Kalman filter has been used, which
choice of parameters, to balance the tempe
***a priori* information and measurements.**
to medicine have been investigated for
within a neonatal head during a hypothe

***Index Terms*—Biomedical measuremen**
filter, microwave radiometry.

I. Introductio

Progress In Electromagnetics Research, PIER 97, 75–93, 2009

ON QUANTITATIVE MICROWAVE TOMOGRAPHY OF FEMALE BREAST

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Abstract—Microwave tomography deserves attention in biomedical imaging, owing to its potential capability of providing a morphological and functional assessment of the inspected tissues. However, such a goal requires the not trivial task of solving a non linear inverse scattering problem. In this paper, the factors affecting the complexity of the inverse problem are exploited to trace guidelines aimed at setting the matching fluid, the frequency range and the number of probes in such a way that the dielectric parameters of female breast tissues can be reliably retrieved. Examples, concerning 2D realistic numerical phantoms obtained by NMR images, are given to asses a posteriori the effectiveness of the proposed guidelines.

ND TECHNIQUES, VOL. 52, NO. 8, AUGUST 2004

Beamforming:
ıor Detection
:oms

. Hagness, *Member, IEEE*,
:n, *Fellow, IEEE*

for detecting nonpalpable early-stage
er, despite significant progress in
ographic technique, well-recognized
Most significantly, there is a need for
specificity, particularly in the case of
reast tissue. Approximately 4%–34%
e missed by conventional mammog-
70% of all breast lesions identified by
to be benign [3]. Other drawbacks
le the risk of accumulating low-dose
epeated scans and patient discomfort
on during the exam. These limitations
lternative or complementary technolo-
ncer detection. One such modality is

The origin of any observed temperature variations is currently a topic of some controversy. For many years it has been known that skin temperature rises of 1 to 3 ^{o}C are associated with some breast tumors (1). The source of this temperature increase has been described as being of metabolic origin by some, and of vascular origin by others. Recent studies with both human and animal subjects have demonstrated that localized surface hot spots can only rarely be attributed to metabolic heat production. They concluded that the thermal patterns over a breast tumor was a reflection of a vascular reaction (43). However, angiographic studies of the breast aimed towards detecting breast cancer have repeatedly proved to be of little value (4), indicating that a consistent angiogenic response is not a characteristic of breast cancers.

The New England
Journal of Medicine

Volume 324 JANUARY 3, 1991 Number 1

TUMOR ANGIOGENESIS AND METASTASIS — CORRELATION IN INVASIVE BREAST CARCINOMA

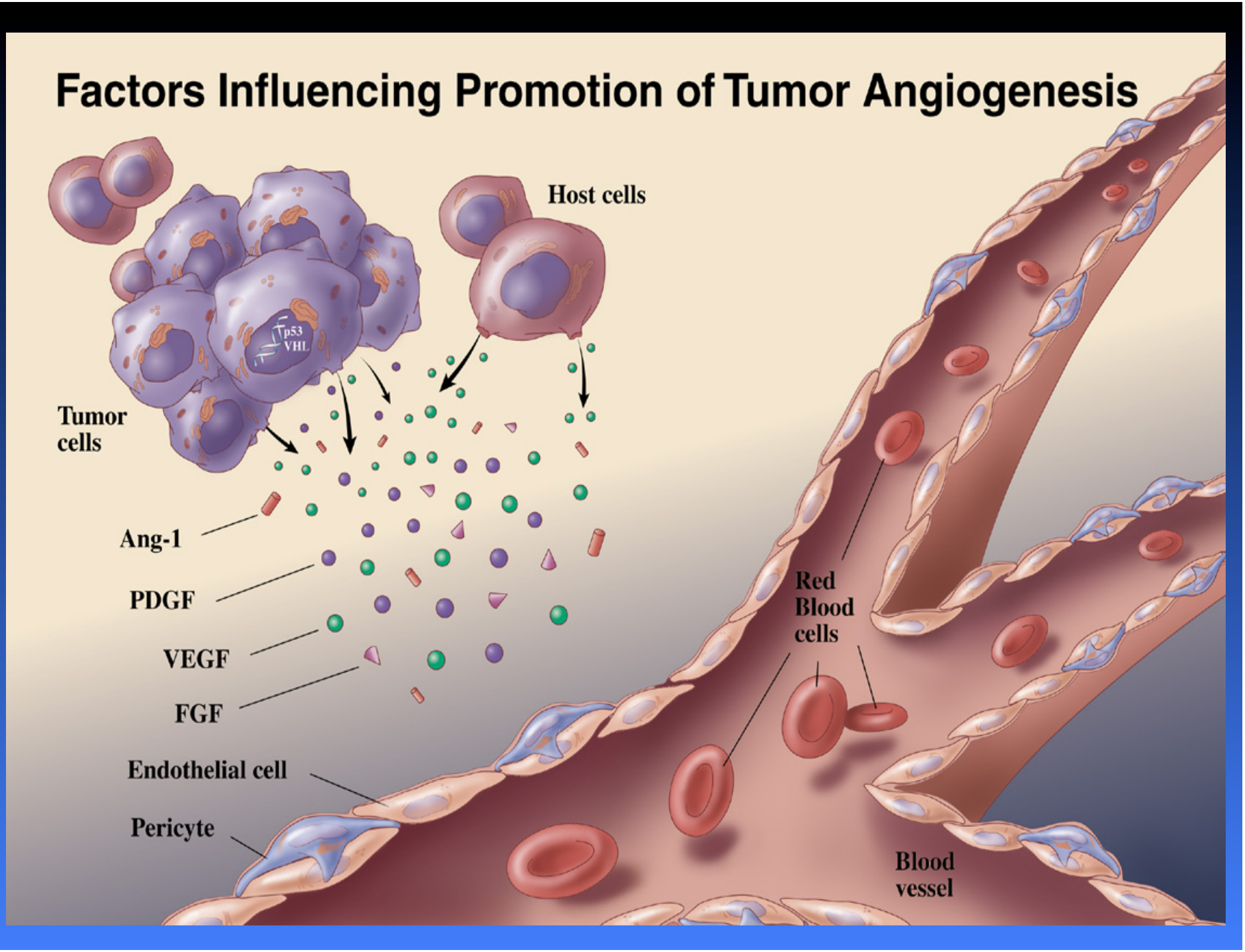
NOEL WEIDNER, M.D., JOSEPH P. SEMPLE, M.D., WILLIAM R. WELCH, M.D., AND JUDAH FOLKMAN, M.D.

Abstract *Background.* Experimental evidence suggests that the growth of a tumor beyond a certain size requires angiogenesis, which may also permit metastasis. To investigate how tumor angiogenesis correlates with metastases in breast carcinoma, we counted microvessels (capillaries and venules) and graded the density of microvessels within the initial invasive carcinomas of 49 patients (30 with metastases and 19 without).

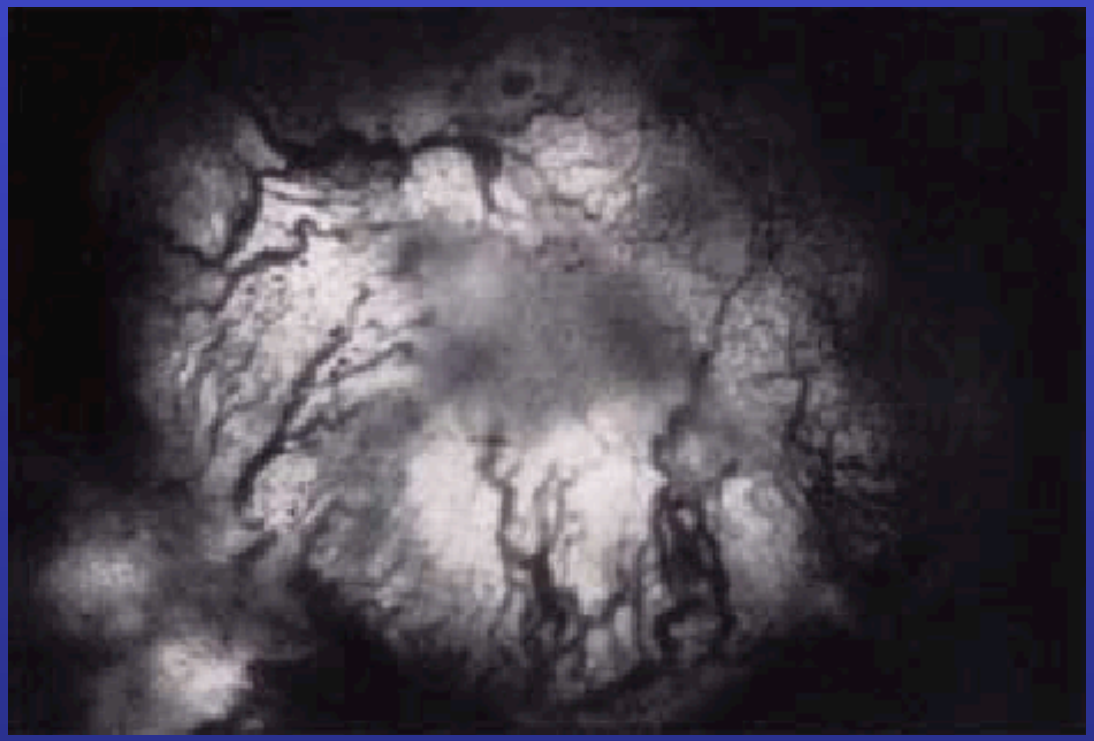
Methods. Using light microscopy, we highlighted the vessels by staining their endothelial cells immunocytochemically for factor VIII. The microvessels were carefully counted (per 200× field), and their density was graded (1 to 4+), in the most active areas of neovascularization, without knowledge of the outcome in the patient, the presence or absence of metastases, or any other pertinent variable.

Results. Both microvessel counts and density grades correlated with metastatic disease. The mean (±SD) count and grade in the patients with metastases were 101±49.3 and 2.95±1.00 vessels, respectively. The corresponding values in the patients without metastases were significantly lower — 45±21.1 and 1.38±0.82 ($P = 0.003$ and $P \leq 0.001$, respectively). For each 10-microvessel increase in the count per 200× field, there was a 1.59-fold increase in the risk of metastasis (95 percent confidence interval, 1.19 to 2.12; $P = 0.003$). The microvessel count and density grade also correlated with distant metastases. For each 10-microvessel increase in the vessel count per 200× field, there was a 1.17-fold increase in the risk of distant metastasis (95 percent confidence interval, 1.02 to 1.34; $P = 0.029$).

Conclusions. The number of microvessels per 200× field in the areas of most intensive neovascularization in an invasive breast carcinoma may be an independent predictor of metastatic disease either in axillary lymph nodes or at distant sites (or both). Assessment of tumor angiogenesis may therefore prove valuable in selecting patients with early breast carcinoma for aggressive therapy. (N Engl J Med 1991; 324:1-8.)


Factors Influencing Promotion of Tumor Angiogenesis
Host cells
p53
VHL
Tumor cells
Ang-1
PDGF
VEGF
FGF
Endothelial cell
Pericyte
Red Blood cells
Blood vessel

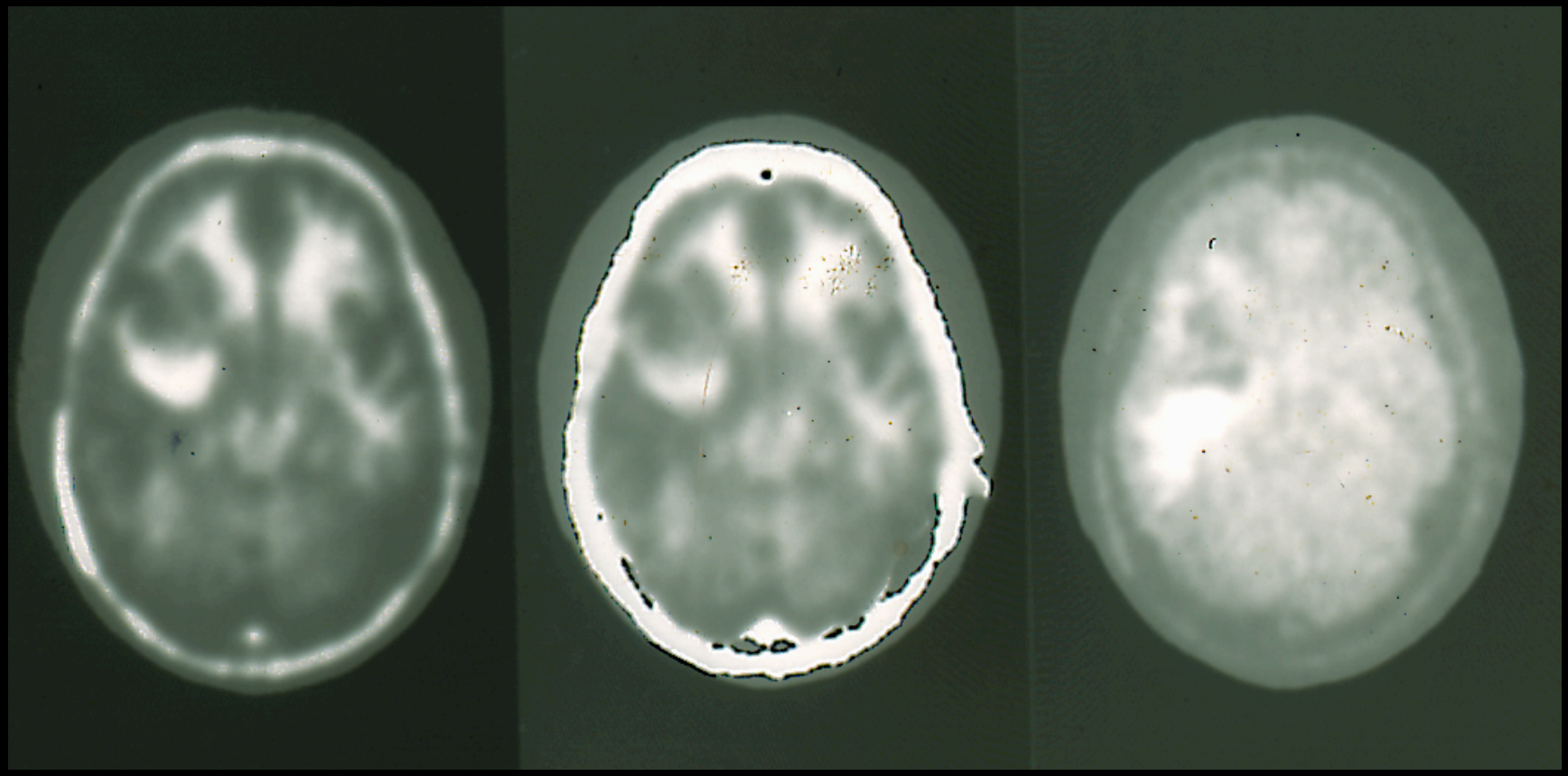
The first *in vivo* images of tumor angiogenesis

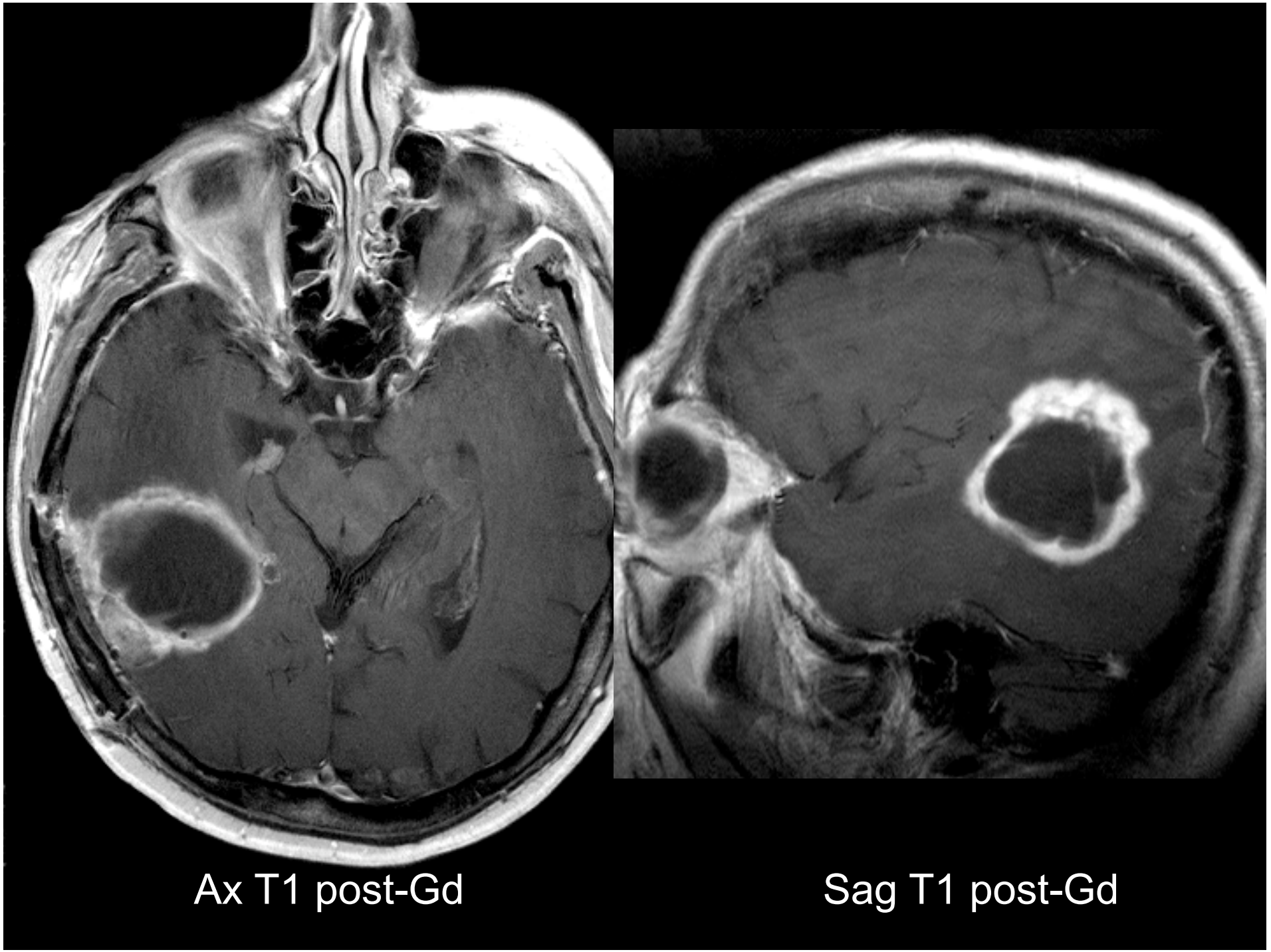


American Journal of Roentgenology
1939 42:891-899

Ide AG, Baker NH, Warren, SL. Vascularization of the Brown Pearce rabbit epithelioma transplant as seen in the transparent ear chamber

MR Imaging circa 1982

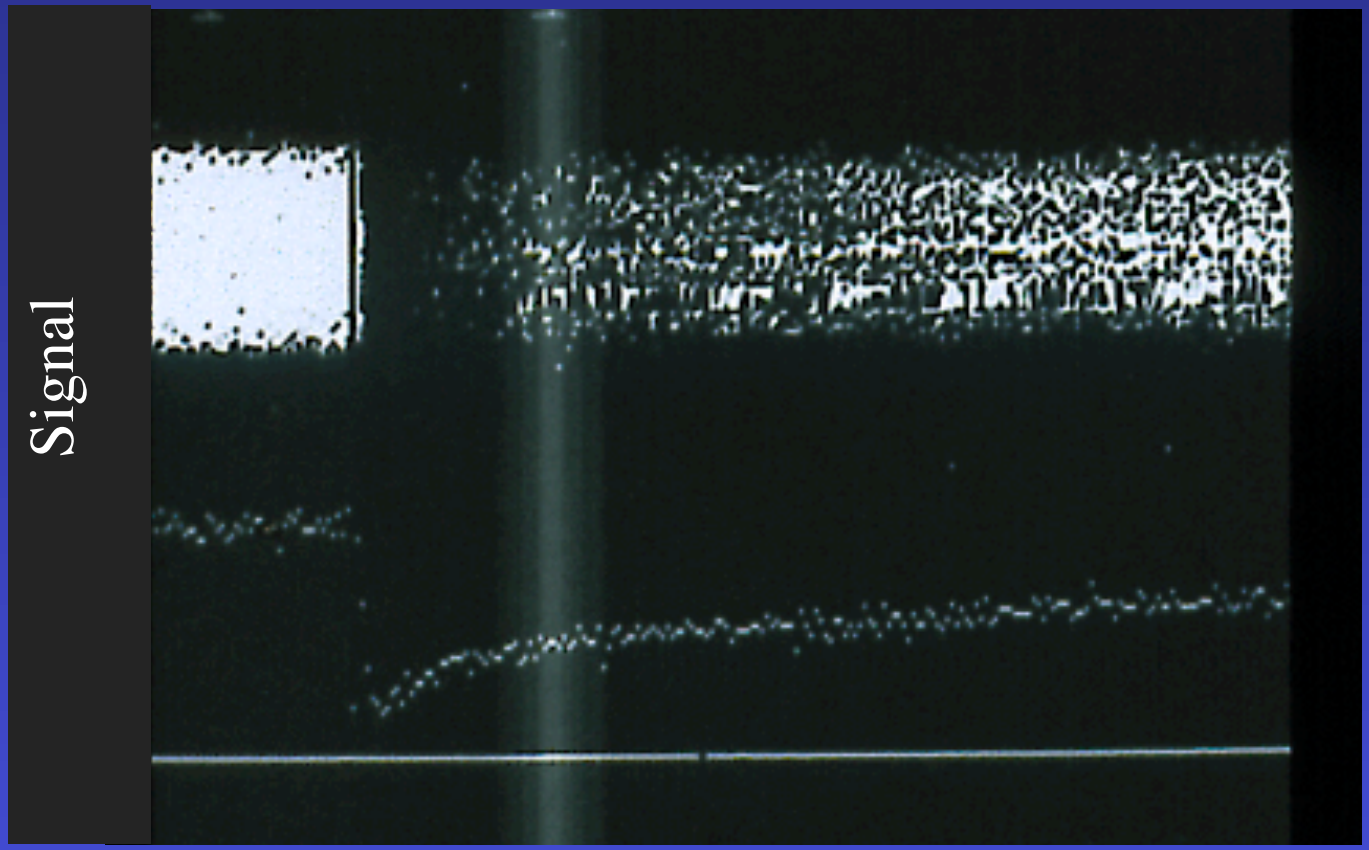



Ax T1 post-Gd
Sag T1 post-Gd

MAGNETIC RESONANCE IN MEDICINE 6, 164–174 (1988)

Dynamic Imaging with Lanthanide Chelates in Normal Brain: Contrast Due to Magnetic Susceptibility Effects

ARNO VILLRINGER,* BRUCE R. ROSEN,† JOHN W. BELLIVEAU,
JEROME L. ACKERMAN, RANDALL B. LAUFFER, RICHARD B. BUXTON,
YONG-SHENG CHAO, VAN J. WEDEEN, AND THOMAS J. BRADY



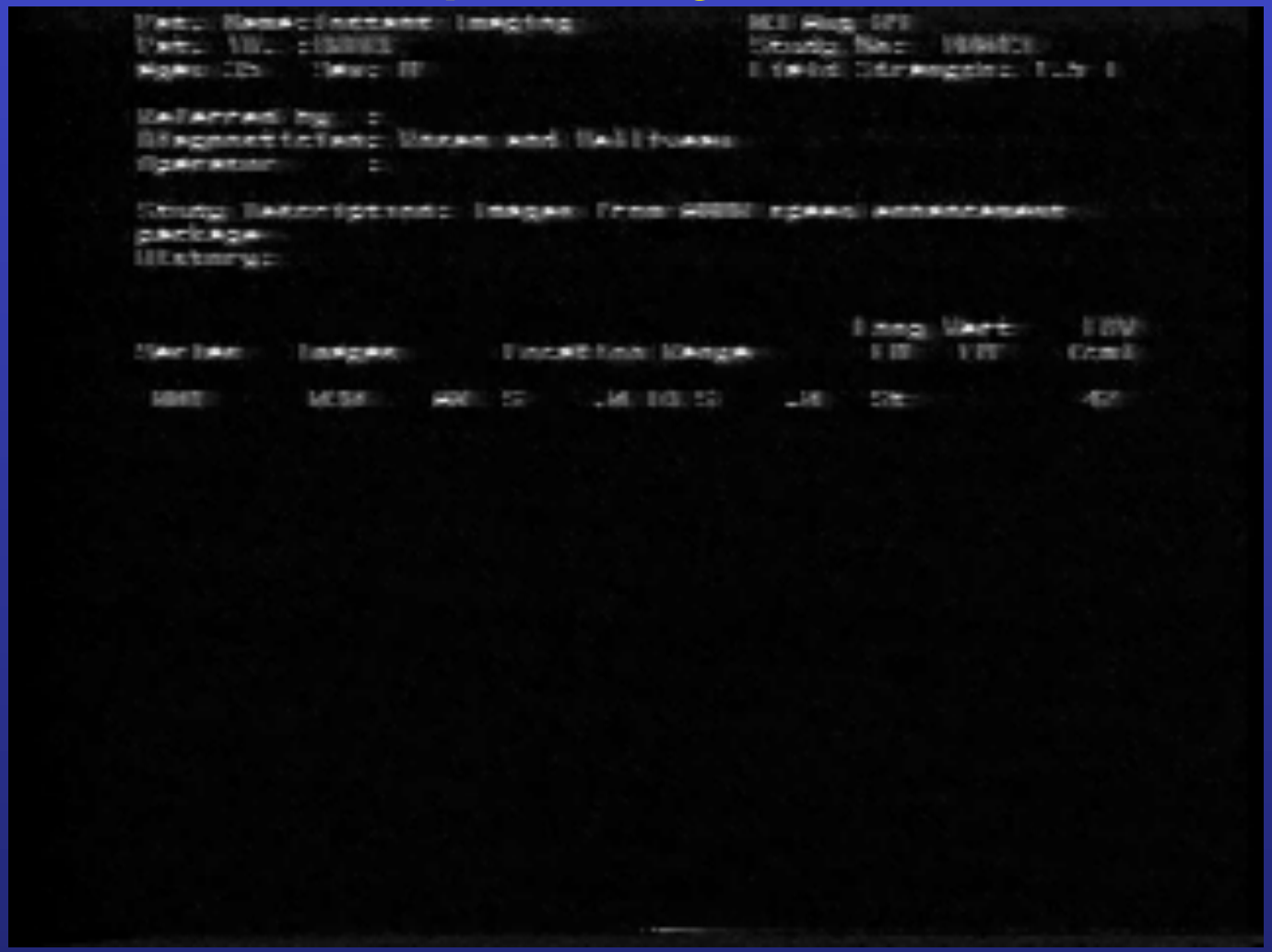
Rat brain signal loss following administration of Gd-DTPA

Mansfield, Peter: "A Personal View of My Involvement in the Development of NMR and the Conception and Development of MRI"

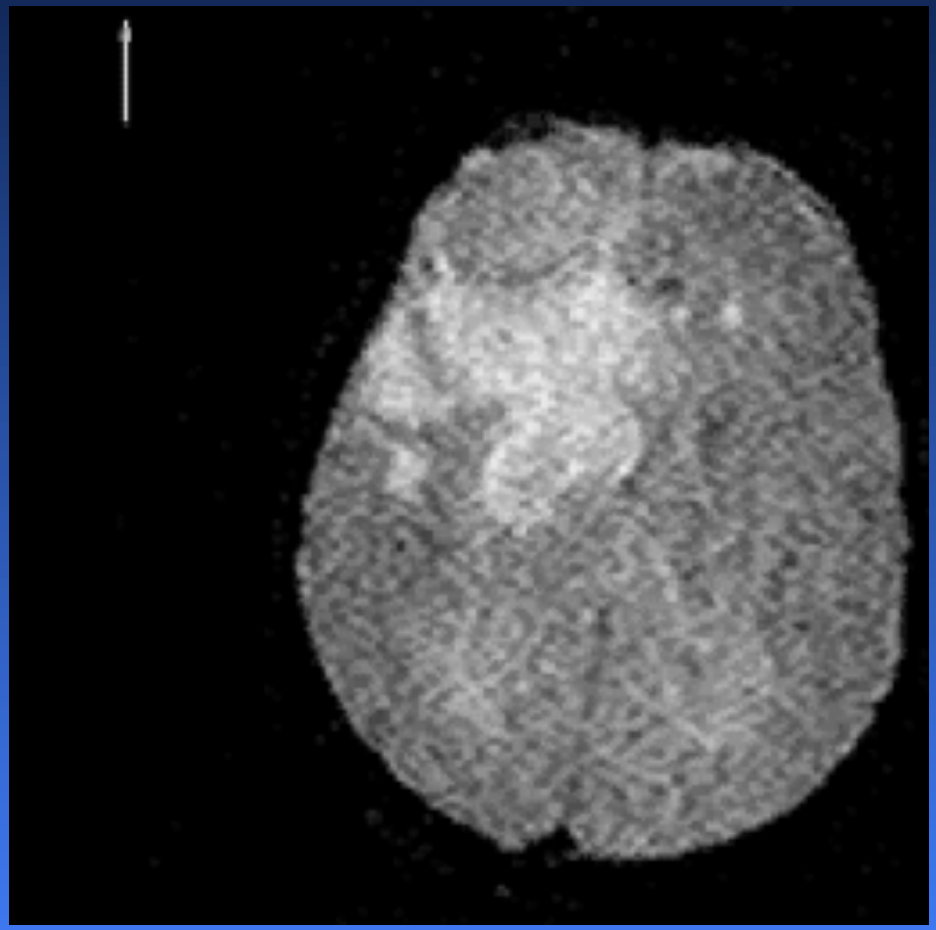
Also, in this intervening period, two former research students of mine, Ian Pykett and Richard Rzedzian, emigrated to the USA and formed a company in Boston called Advanced NMR Systems. We subsequently joined the company's prospectus of building and marketing an EPI machine. Although several prototype machines were produced and installed at various sites, EPI never really took off in a big way commercially during that period.

"Nevertheless, an early version of EPI was implemented by Ian Pykett in 1977. He succeeded in obtaining crude snapshot images of a test-tube phantom and later a live human finger."

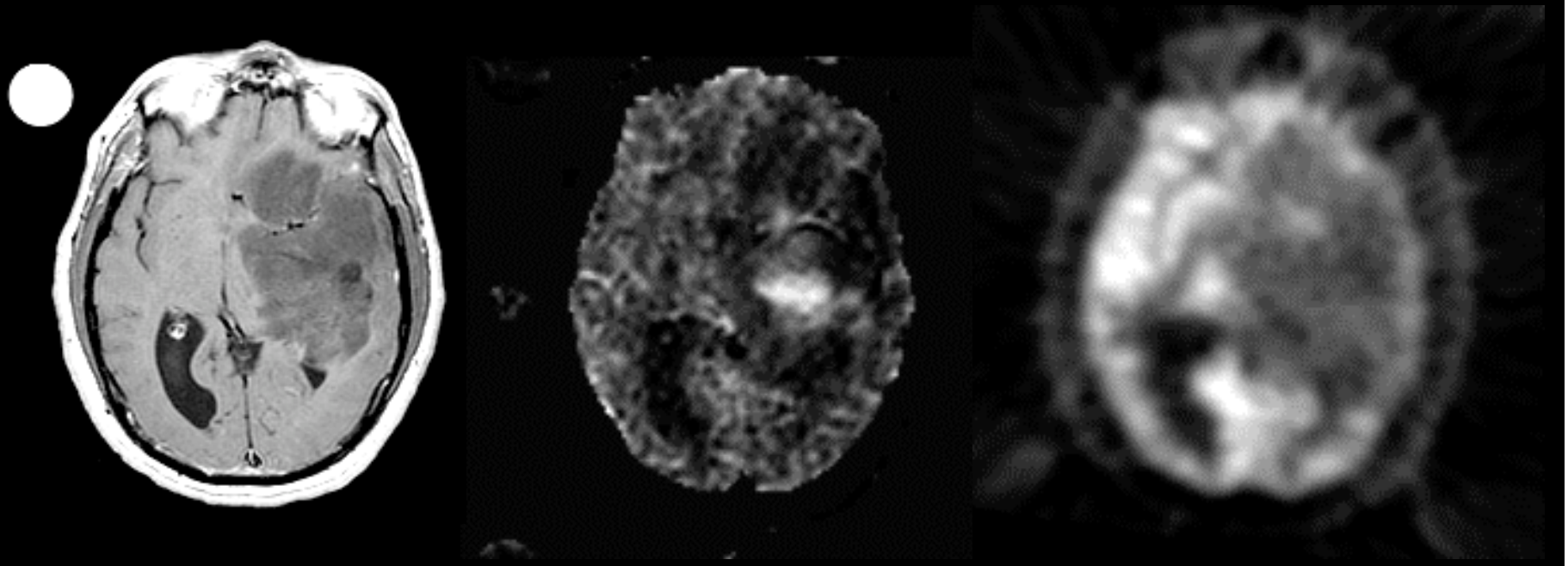
EPI Acquisition of Dynamic Susceptibility Contrast



Dynamic Susceptibility Contrast Imaging of Tumor Blood Volume

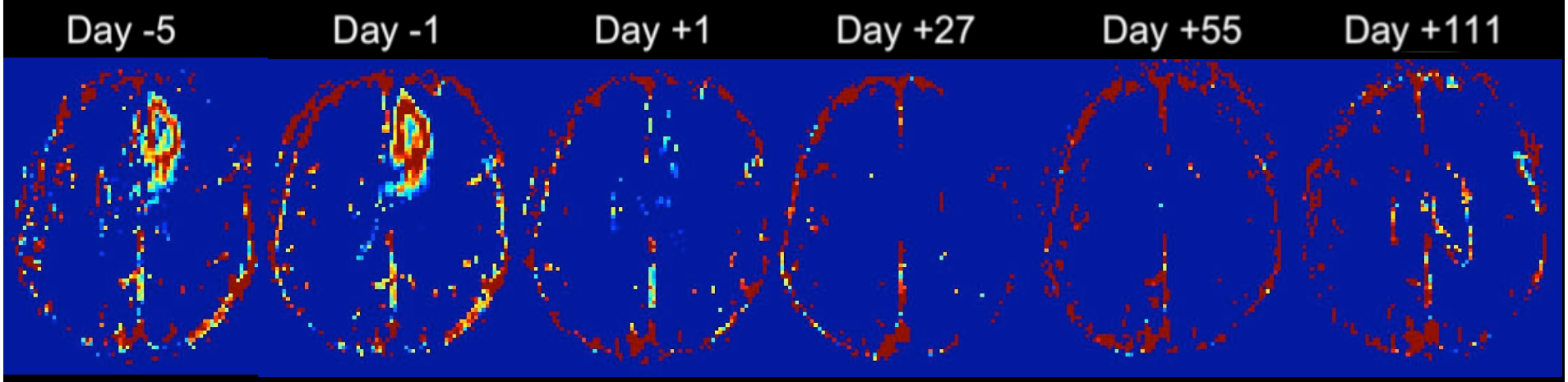


Malignant Dedifferentiation

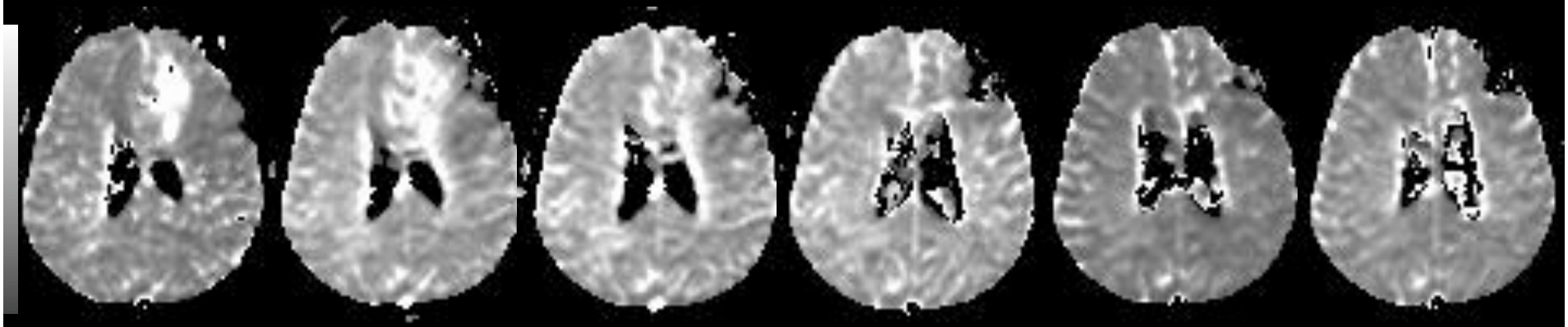


POST GADO CBV FDG

Evidence of Vascular Normalization with VEGF blockade (AZD2171, cediranib)



K-Trans Permeability Map

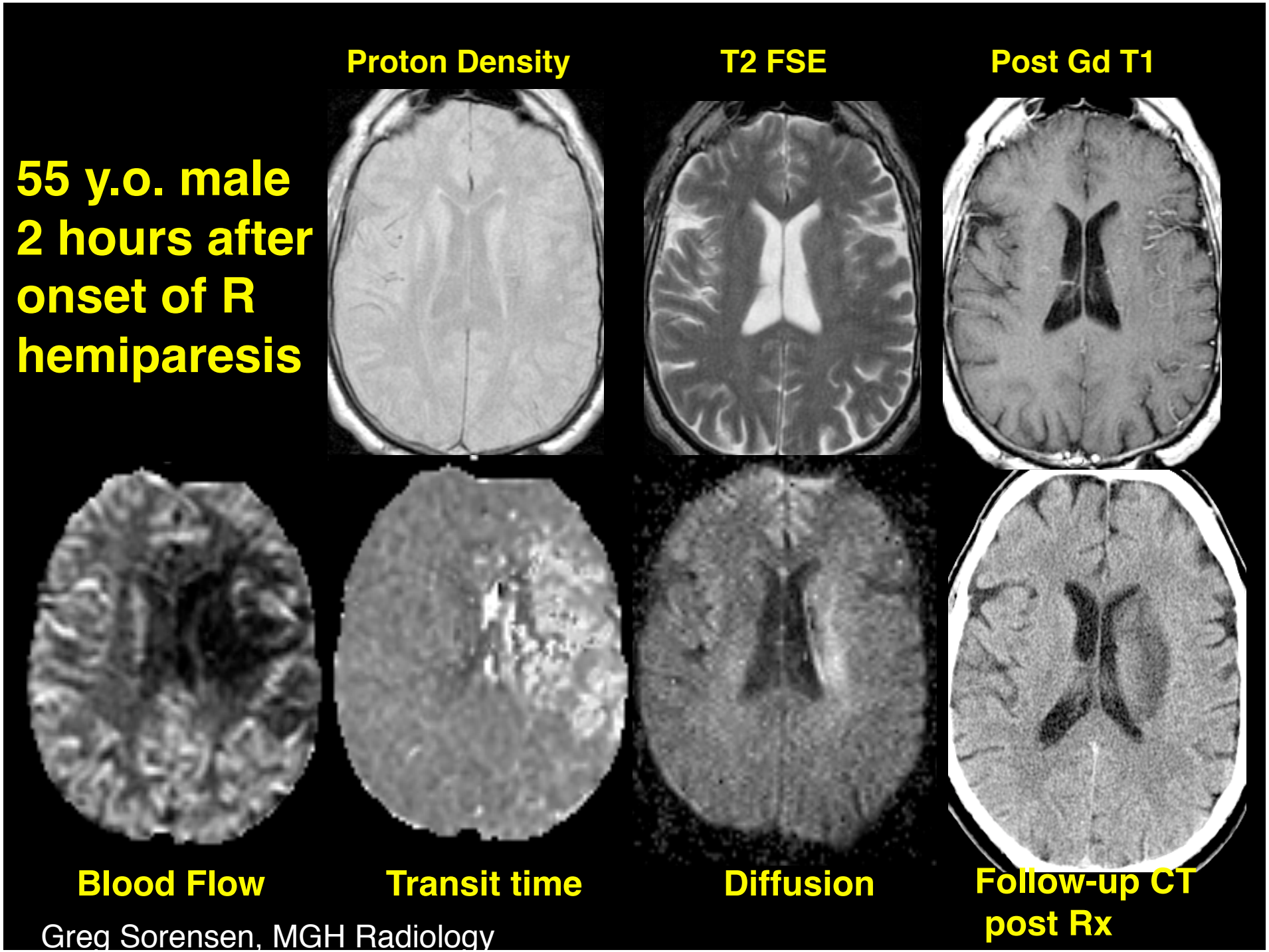


Relative Vessel Size

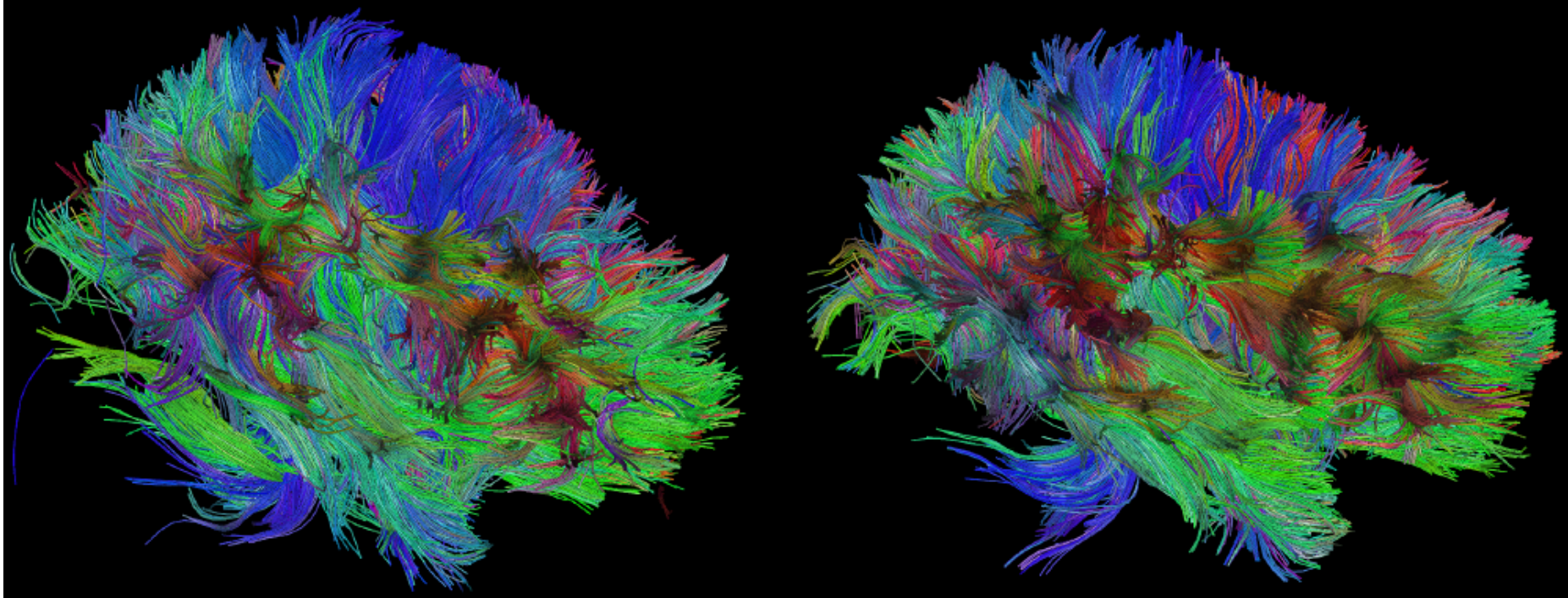
Supported by US PHS Grant R21-CA117079

3T TimTrio

Batchelor / Jain / Wen / Zhang / Benner / Chen / Sorensen / MGH-Martinos


55 y.o. male
2 hours after
onset of R
hemiparesis
Proton Density
T2 FSE
Post Gd T1
Blood Flow
Transit time
Diffusion
Follow-up CT
post Rx
Greg Sorensen, MGH Radiology

Diffusion Tractography



A – B = ??

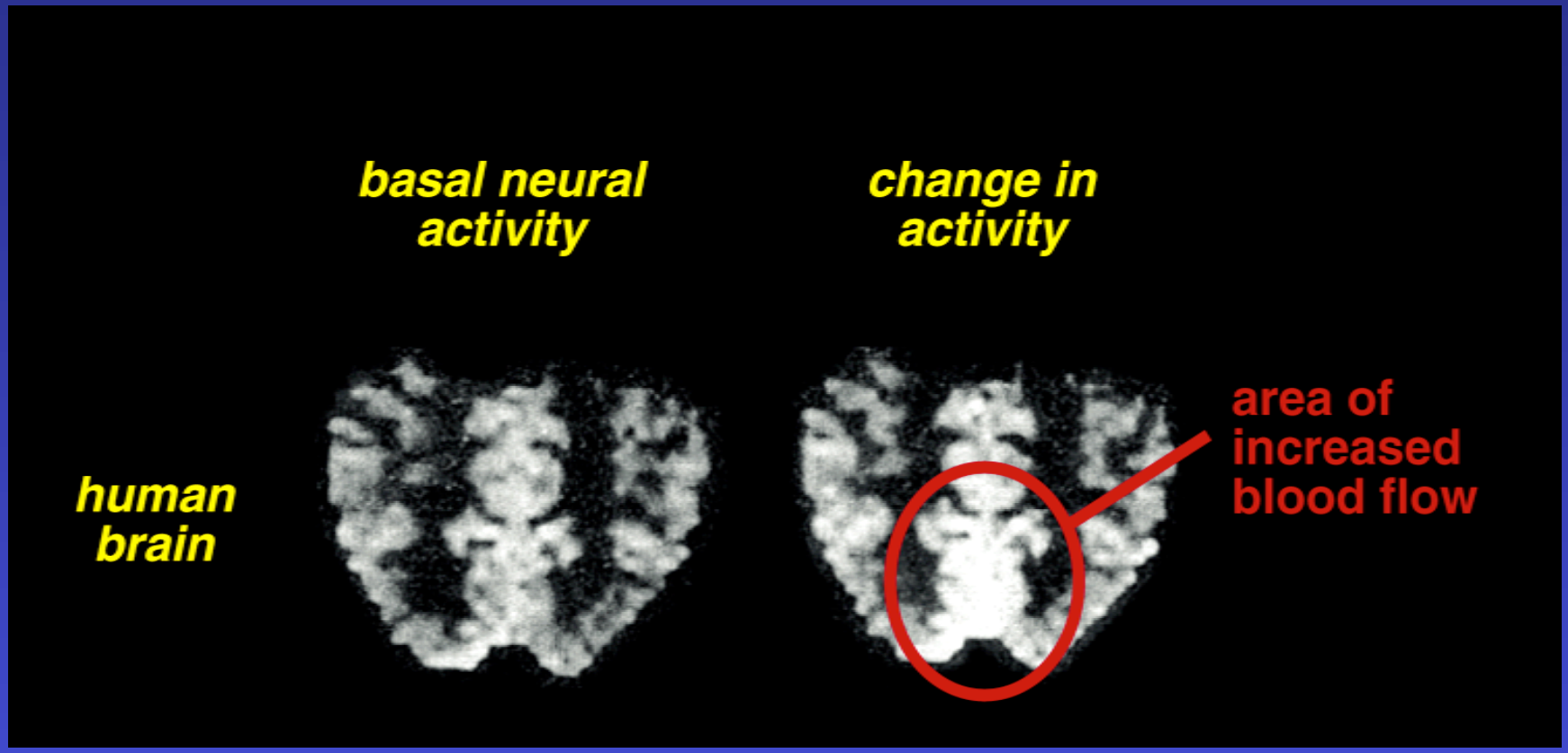


Image courtesy Jack Belliveau


American
Association for the
Advancement of
Science
SCIENCE
1 November 1991
Vol. 254 ■ Pages 671-768

Functional Mapping of the Human Visual Cortex by Magnetic Resonance Imaging

J. W. Belliveau,* D. N. Kennedy, R. C. McKinstry, B. R. Buchbinder, R. M. Weisskoff, M. S. Cohen, J. M. Vevea, T. J. Brady, B. R. Rosen

Knowledge of regional cerebral hemodynamics has widespread application for both physiological research and clinical assessment because of the well-established interrelation between physiological function, energy metabolism, and localized blood supply. A magnetic resonance technique was developed for quantitative imaging of cerebral hemodynamics, allowing for measurement of regional cerebral blood volume during resting and activated cognitive states. This technique was used to generate the first functional magnetic resonance maps of human task activation, by using a visual stimulus paradigm. During photic stimulation, localized increases in blood volume (32 ± 10 percent, n = 7 subjects) were detected in the primary visual cortex. Center-of-mass coordinates and linear extents of brain activation within the plane of the calcarine fissure are reported.

Science, New Series, Vol. 254, No. 5032. (Nov. 1, 1991), pp. 716-719.

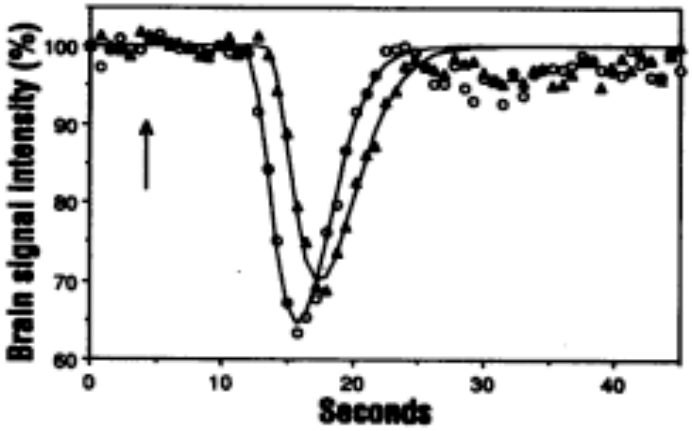
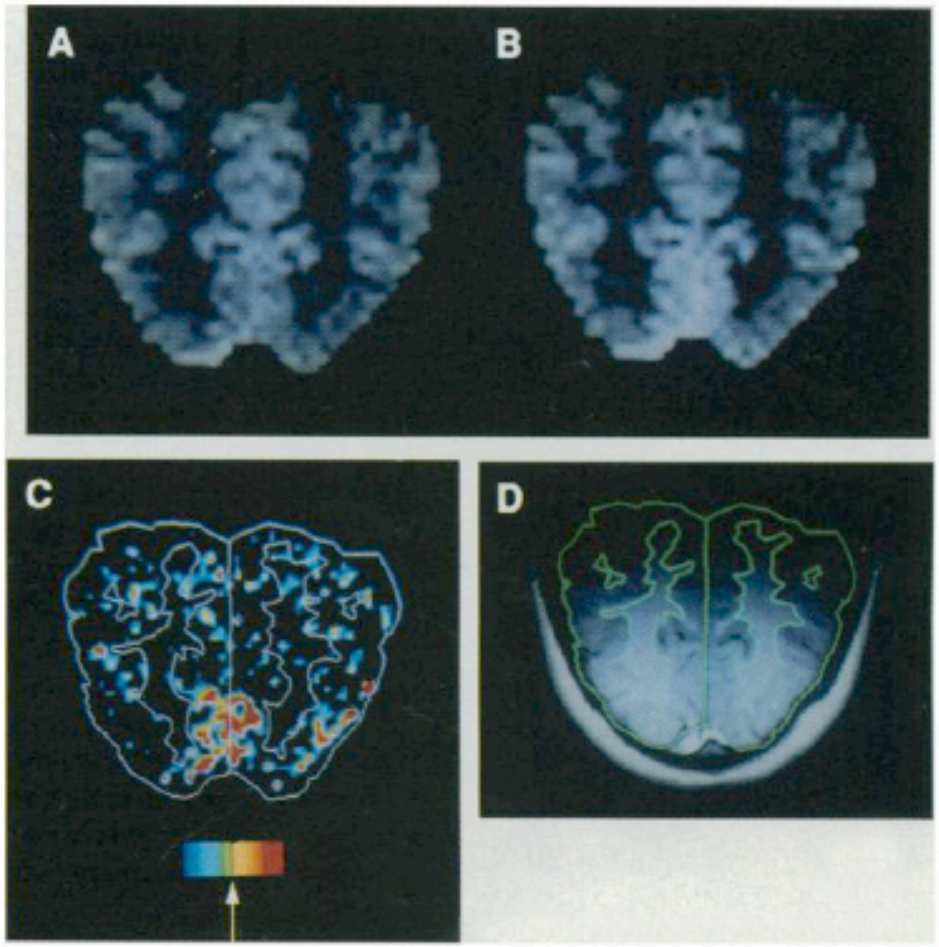
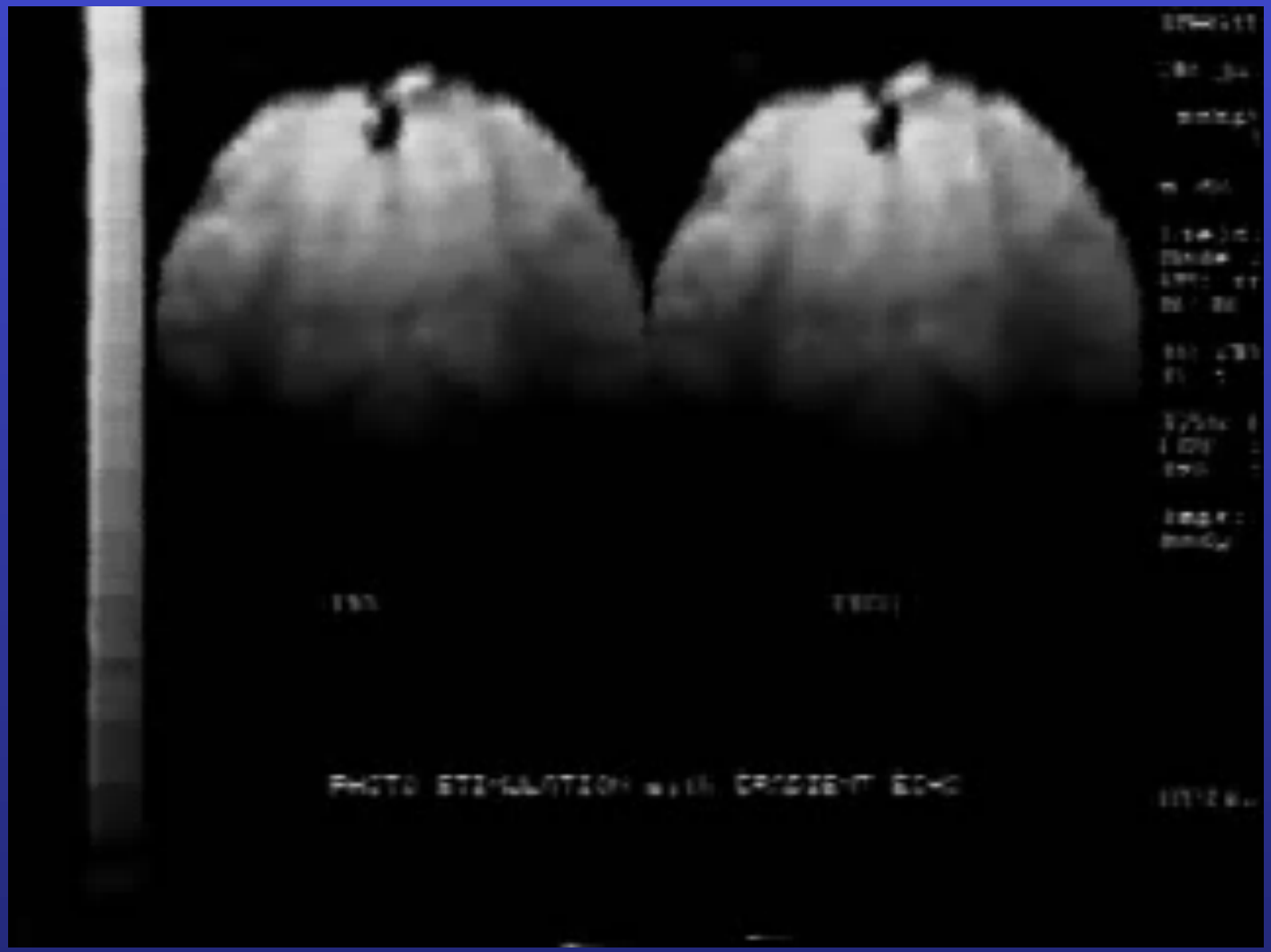


Fig. 2. Changes in NMR brain signal intensity during the first-pass transit of intravenously administered paramagnetic contrast agent (0.1 mmol/kg $Gd(DTPA)^{2-}$, at arrow). Sixty images were acquired in 45 seconds (▲, resting; ○, activated). Baseline normalized signal intensity changes from a single subject are shown for a single 3 by 3 by 10 mm voxel within the visual cortex during rest (darkness) and during 7.8-Hz photic stimulation. The activated state is characterized by a larger blood volume (area under curve).



"These experiments demonstrate the potential of magnetic resonance techniques for high-resolution mapping of brain areas involved in cognitive processing. Further improvements in both spatial resolution and sensitivity of the NMR method can be expected with the ongoing development of localized gradient coils and phased array receiver coils. The sensitivity of our NMR technique to changes in blood volume, as distinguished from changes in blood flow in previous radionuclide studies, offers the possibility of performing continuous serial imaging of cortical function with subsecond temporal resolution using intravascular contrast agents at equilibrium within the vascular space".



Proc. Natl. Acad. Sci. USA
Vol. 89, pp. 5675–5679, June 1992
Neurobiology

Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation

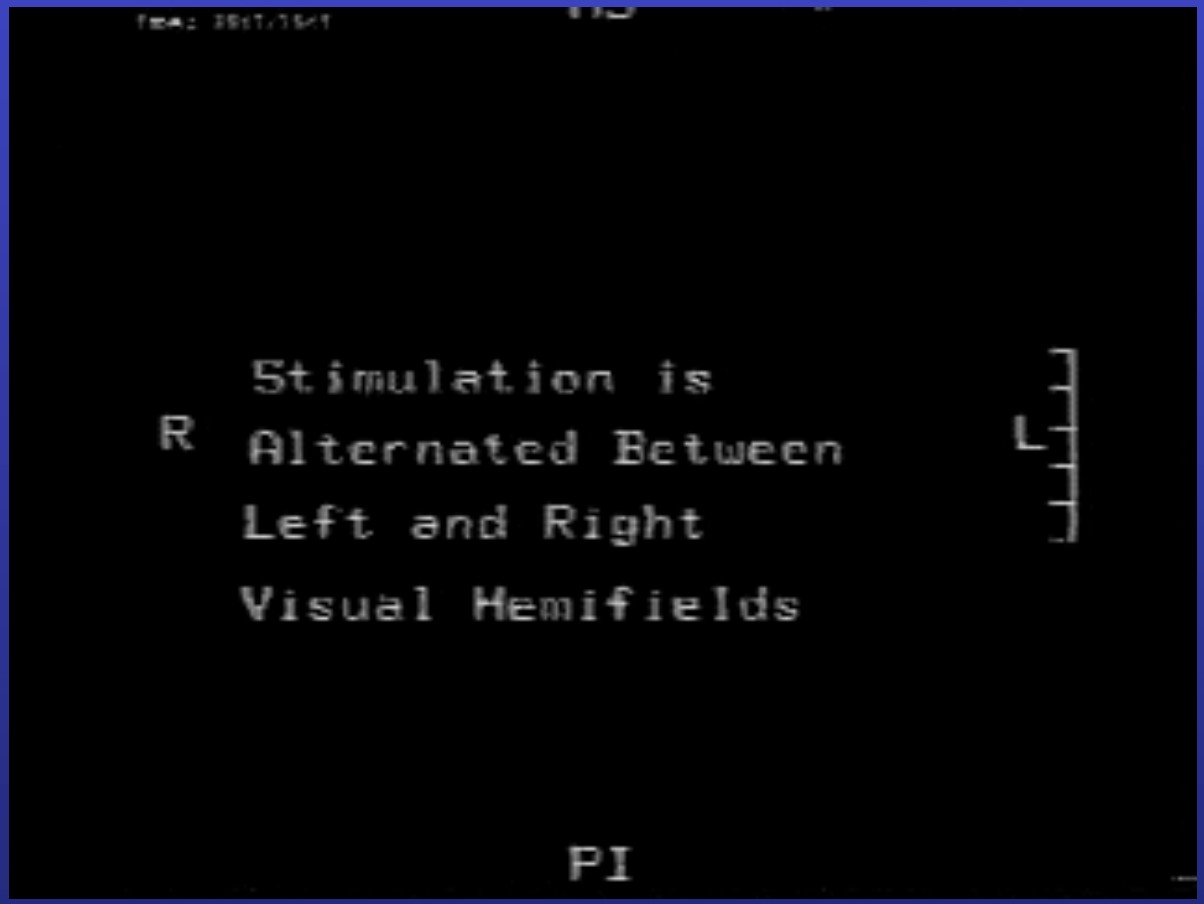
KENNETH K. KWONG†, JOHN W. BELLIVEAU†, DAVID A. CHESLER†, INNA E. GOLDBERG†, ROBERT M. WEISSKOFF†, BRIGITTE P. PONCELET†, DAVID N. KENNEDY†, BERNICE E. HOPPEL†, MARK S. COHEN†, ROBERT TURNER‡, HONG-MING CHENG§, THOMAS J. BRADY†, AND BRUCE R. ROSEN†

†MGH–NMR Center, Department of Radiology, Massachusetts General Hospital and Harvard Medical School, Charlestown, MA 02129; ‡National Institutes of Health, Laboratory of Cardiac Energetics, National Heart, Lung, and Blood Institute, Bethesda, MD 20892; and §Howe Laboratory of Ophthalmology, Massachusetts Eye and Ear Infirmary and Harvard Medical School, Boston, MA 02114

Communicated by David H. Hubel, March 26, 1992

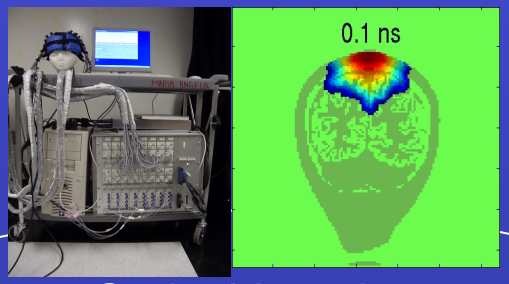
ABSTRACT Neuronal activity causes local changes in cerebral blood flow, blood volume, and blood oxygenation. Magnetic resonance imaging (MRI) techniques sensitive to changes in cerebral blood flow and blood oxygenation were developed by high-speed echo planar imaging. These techniques were used to obtain completely noninvasive tomographic maps of human brain activity, by using visual and motor stimulus paradigms. Changes in blood oxygenation were detected by using a gradient echo (GE) imaging sequence sensitive to the paramagnetic state of deoxygenated hemoglobin. Blood flow changes were evaluated by a spin-echo inversion recovery (IR), tissue relaxation parameter T_1-sensitive pulse sequence. A series of images were acquired continuously with the same imaging pulse sequence (either GE or IR) during task activation. Cine display of subtraction images (activated minus baseline) directly demonstrates activity-induced changes

Hemifield fMRI

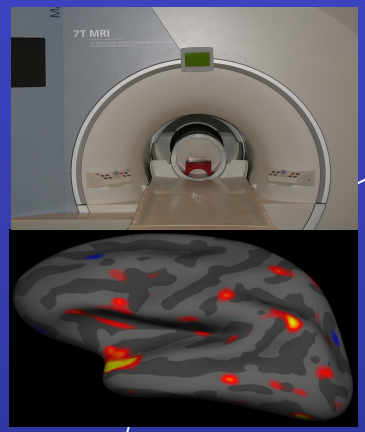


Functional Imaging: Across Space and Time

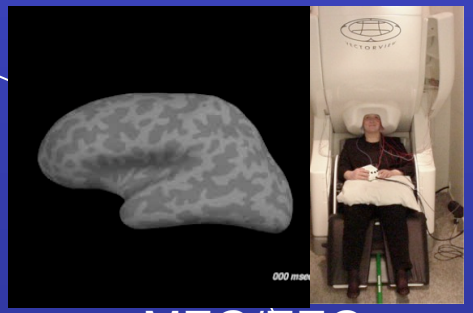
Anatomy, Physiology, Metabolism, Electrophysiology, Neurochemistry



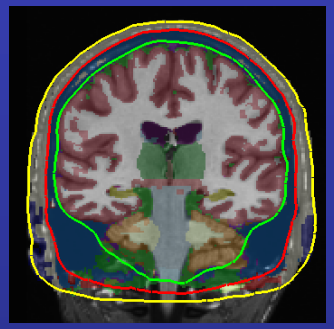
Optical Imaging



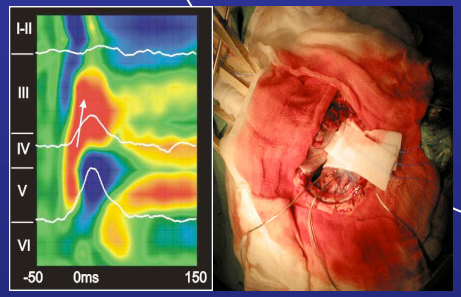
High-Field fMRI



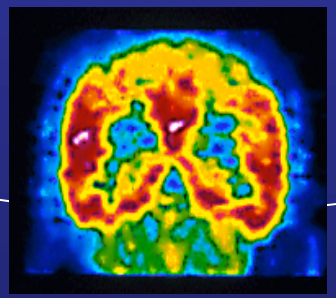
MEG/EEG



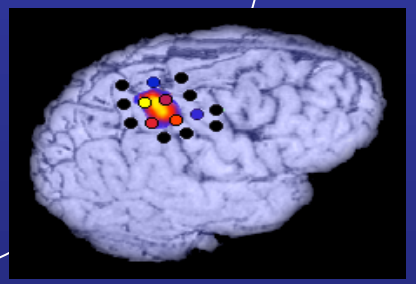
Anatomic MR



Cortical Stim



PET



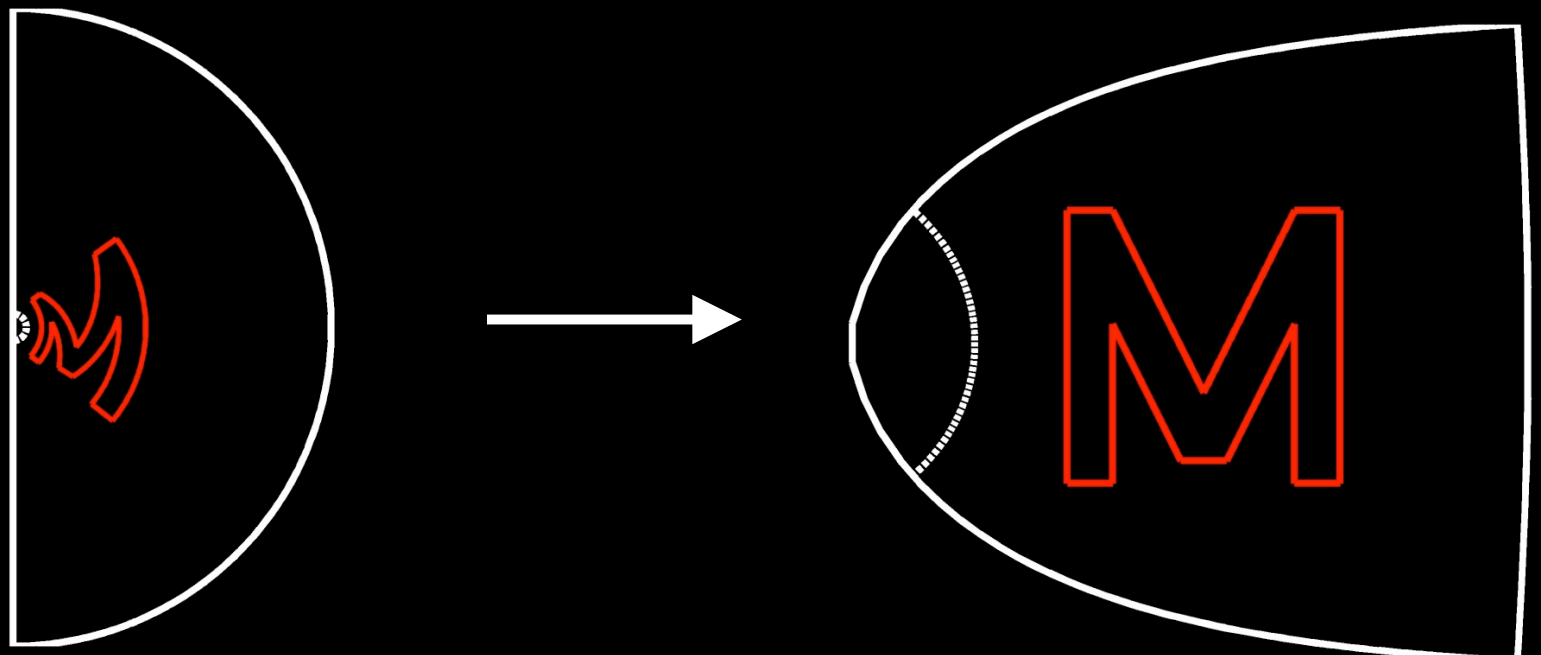
TMS

V1 Resolution test: “M”

Jon Polimeni, and collab. w/ E. Schwartz

pre-warped stimulus

desired activity pattern on flattened cortex



contralateral visual hemi-field

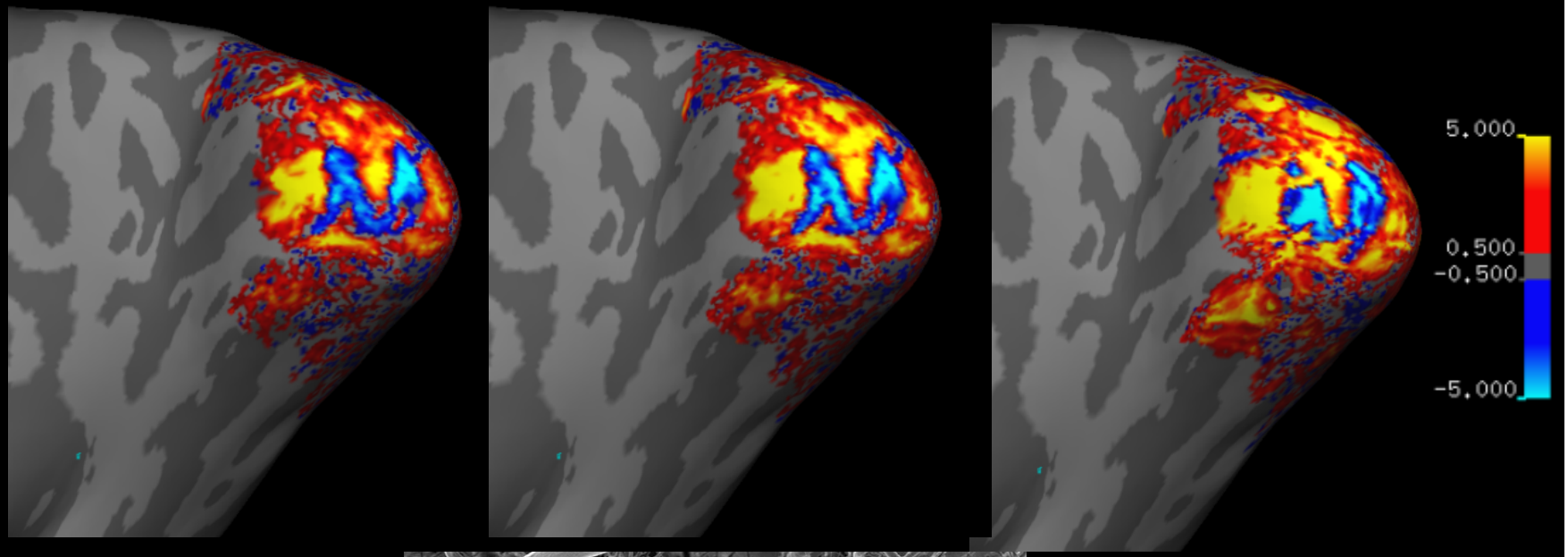
primary visual cortex (V1)

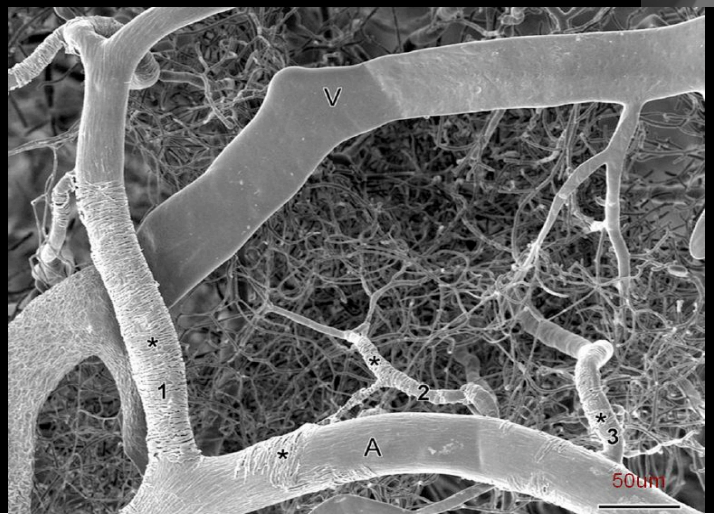
Activation pattern fidelity as function of cortical depth

Near WM

Center lamina

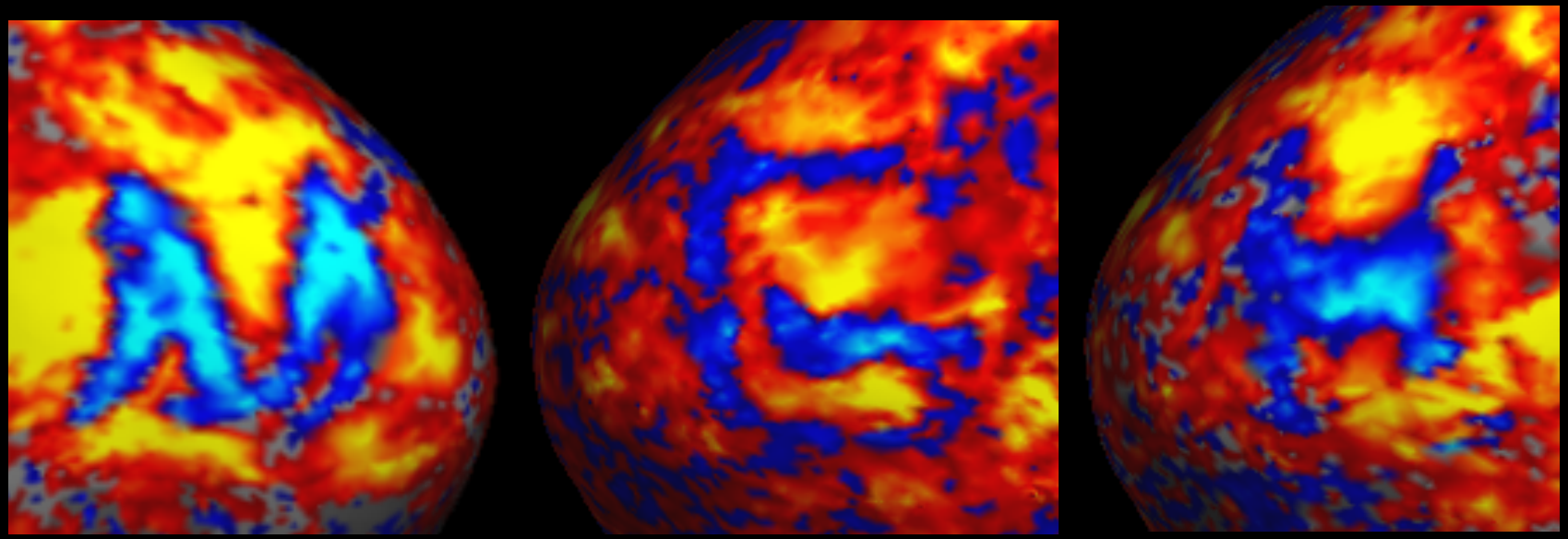
Near pial surface





Harrison et al, Chinhcilla auditor cortex, Cereb. Cortex 2002, 12, p225

Tried to Spell:
“MGH Center for Functional Neuroimaging Technologies”



MICROWAVE THERMOGRAPHY FOR THE DETECTION OF BREAST CANCER: A DISCUSSION AND EVALUATION OF A 6 GHZ SYSTEM

by

BRUCE ROBERT ROSEN

A.B., Harvard University
(1977)

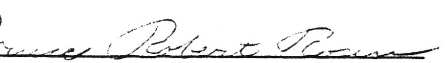
SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF

MASTER OF SCIENCE IN PHYSICS

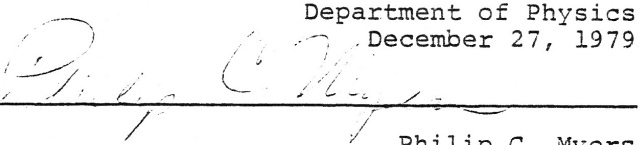
at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

January 1980

Signature of Author 

Department of Physics
December 27, 1979

Certified by 

Philip C. Myers
Thesis Supervisor

Accepted by _____

George F. Koster
Chairman, Graduate Committee

ACKNOWLEDGEMENTS

I would like to thank those people without whose help the completion of this thesis would have been impossible. First, I would like to thank Professor Philip Myers, first for his help in arranging for my leave of absence from Medical School, and second for his guidance and advice throughout my tenure at M.I.T. Next, I would like to thank Professor Alan Barrett, who also provided useful insights for the analysis of the patient data and general assistance when Prof. Myers was away.

I would also like to give special thanks to Mr. Jack Barrett,who was my mentor and constant source of information in the practical aspects of microwave engineering. Mr. Cosmo Papa also was an endless source of assistance in and around the laboratory, and I am much in his debt as well.

Thanks are also due to Professor Kyle, Dr. Sadowsky, Dr. Aaronson, Mac Lindsay, Peter Wright, Andy Schwartz and John Daly all of whom provided their time and effort in helping me aquire skills and information.

Thanks

ROC Curve

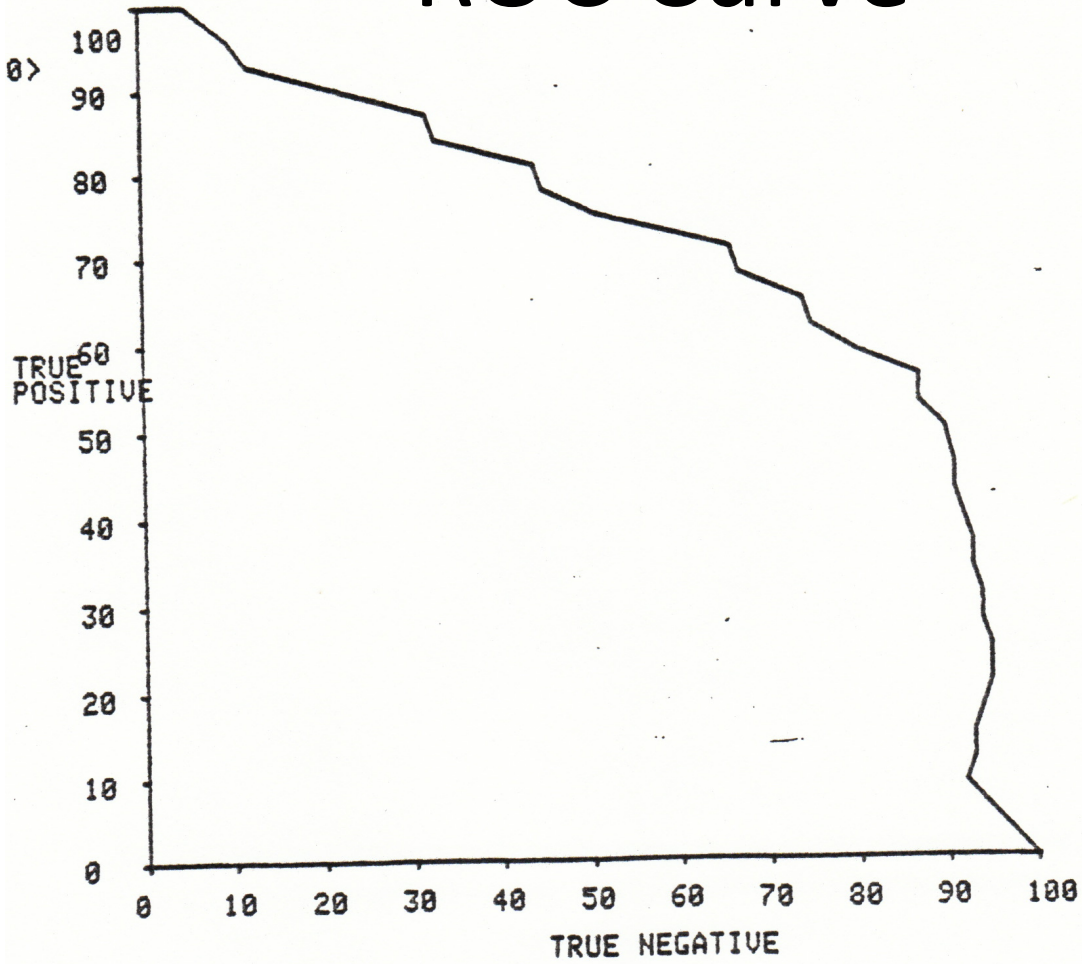


FIGURE 27. ROC CURVE WITH LINEAR DISCRIMINANT FUNCTIONS USING AVEDIF, MAXDIF, AND HOTSPOT.

More ROC Curves

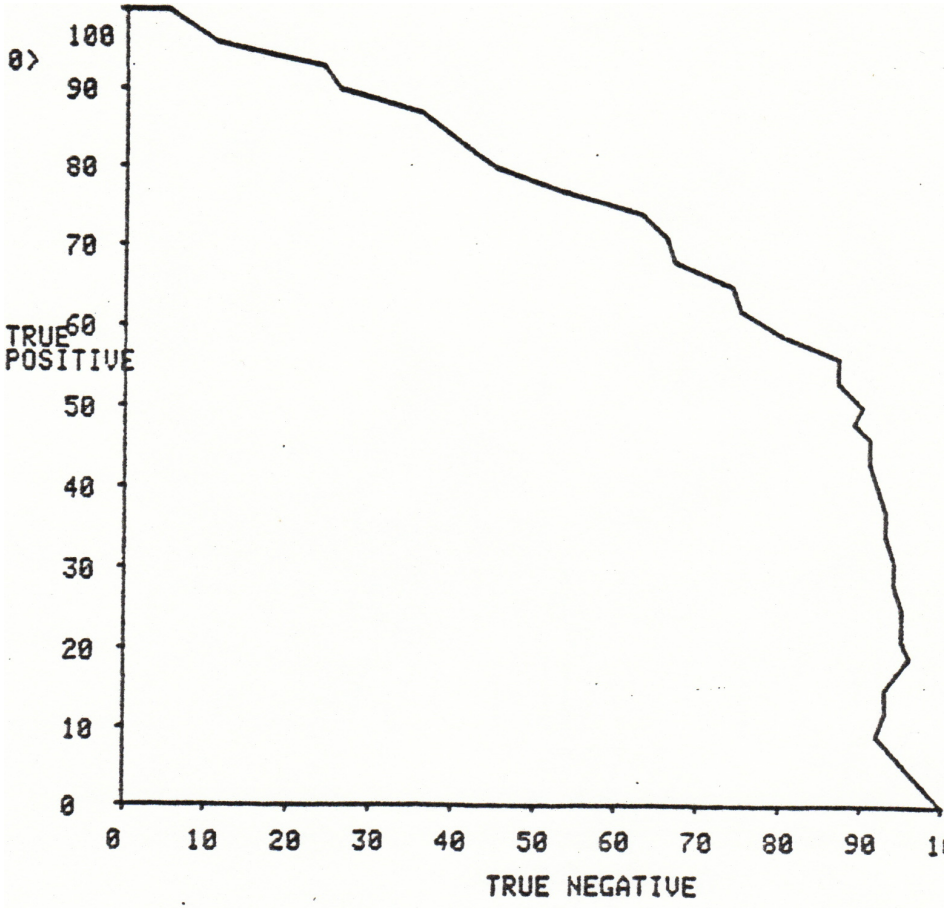


FIGURE 29. ROC CURVE FOR THE BEST COMBINED RESULTS (LINEAR AND "OR" FUNCTIONS) USING AVEDIF, MAXDIF, AND HOTSPOT.

“Star” Diagrams – Cancer vs. Normal

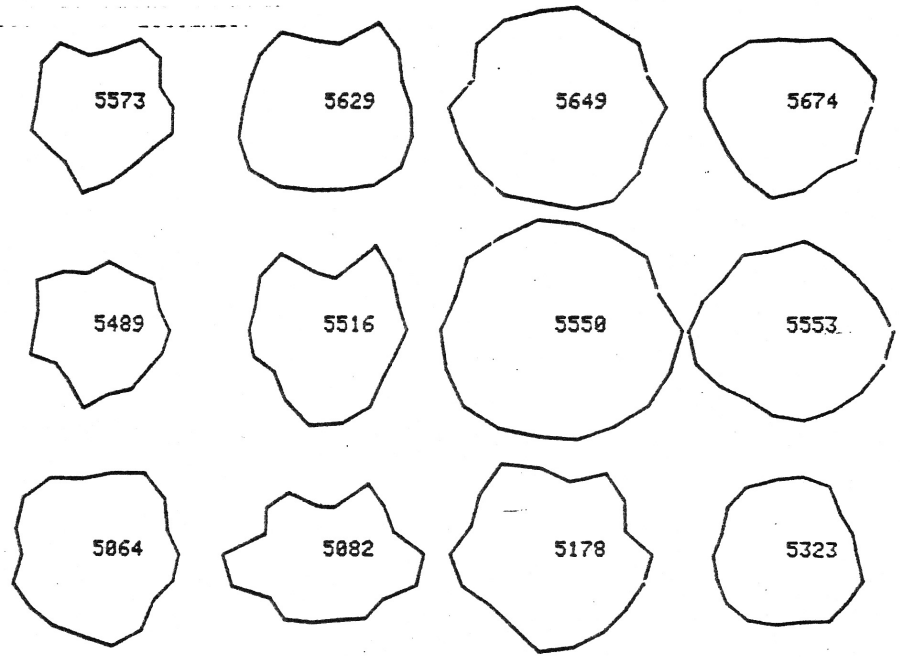


FIGURE 45. STAR DIAGRAMS FOR "INNER GROUP" CANCERS

Left side measurements on diagrams left side.
Microwave exam numbers given inside diagrams.

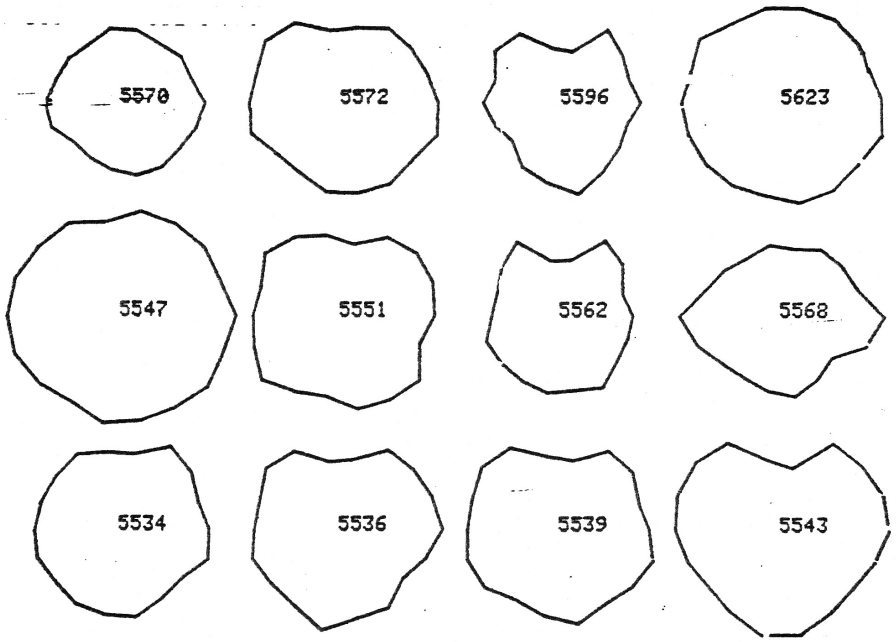


FIGURE 46. STAR DIAGRAMS FOR "INNER GROUP" NORMALS.

Peak Power vs. Depth

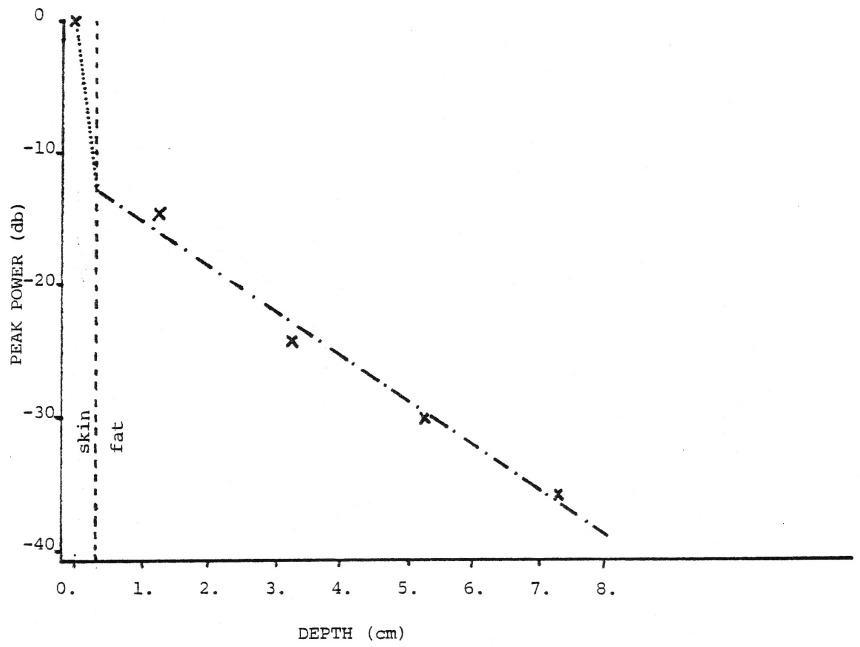


FIGURE 7. PEAK POWER VERSUS DEPTH

-·-· = Attenuation due to fat
···· = Estimated attenuation due to skin

Contour Map at Aperture

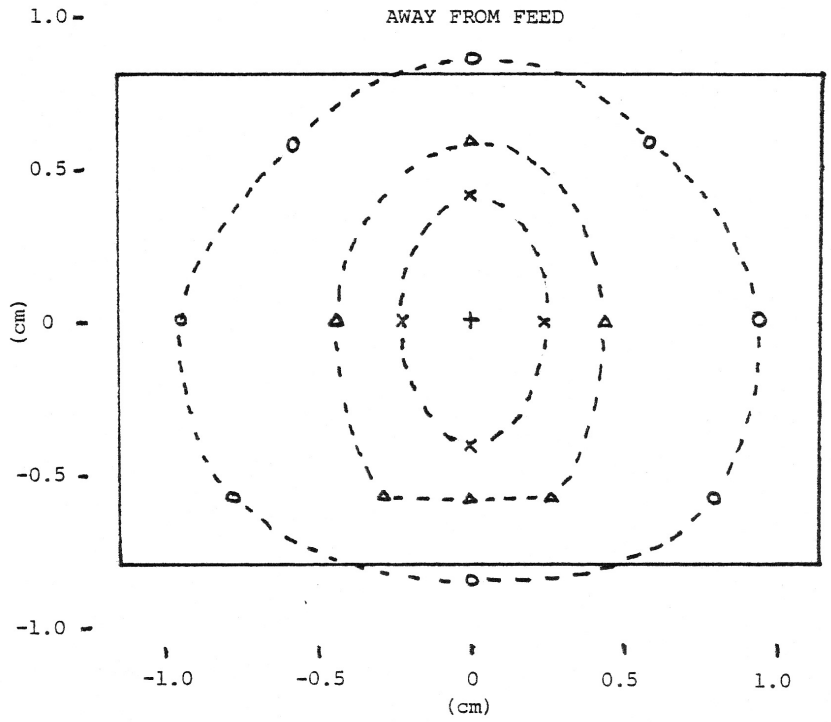


FIGURE 10. CONTOUR MAP AT APERTURE

X = 1 db contour
Δ = 3 db contour
o = 10 db contour
+ = peak power point

Waveguide dimensions outlined