Thermography and breast cancer detection

by H.J. ISARD

J. Gershon-Cohen Breast Clinic, Division of Radiology; Albert Einstein Medical Center; Philadelphia (U.S.A.)

Summary. In symptomatic women thermography (T.) has shown to improve accuracy when used in conjunction with mammography and physical examination. For screening asymptomatic women T. serves as a significant risk marker for minimal and early stage breast cancer. Among 5,000 self selected asymptomatic women, 62 patients with breast cancer were found, 85% of whom had abnormal or equivocal T. criteria.

Key WOrdS: thermography, breast cancer, screening.

A) INTRODUCTION

The importance of breast cancer in women in the U.S. is clearly demonstrated by the fact that 7% (l/14 women) are afflicted at some time during their lives. It is the most frequent site of cancer in women and is responsible for the greatest number of cancer deaths. In an effort to improve mortality and morbidity by early detection, a large scale program, the Breast Cancer Detection Demonstration Project (B.C.D.D.P.) was started in the U.S. in 1973 under the auspices of the National Cancer Institute and the American Cancer Society. Self selected asymptomatic women between the ages of 3.5 and 74 were invited to participate and undergo clinical examination (C. E.) mammography (M.) and thermography (T.) in addition to answering a questionnaire, and to have the examinations repeated for 5 annual screenings.

M. had proved its value in screening when used in conjunction with C.E. in the program of the Health Insurance Plan in New York wherein a reduction in mortality from breast cancer in the screened group was demonstrated. In the planning of the B.C.D.D.P. there was interest in clarifying the potential of T. to serve as a substitute for M. in the routine phase of screening with M. being used for suspicious cases.

Reports of results of breast T. in women with cancer can be found in the medical literature from many countries throughout the world, but these statistics do not reflect experience with large scale screening programs.

It is too early to make accurate predictions of definite benefits resulting from the B.C.D.D.P. but it is already apparent that minimal cancers with favorable prognosis are being found. Recommendations for aspiration procedures or breast biopsy were based upon C.E. and M. and T. was recorded as either normal or abnormal for correlative purposes, which resulted in an average rate of 21.9% abnormality. Unfortunately many of the T. readers had little if any prior experience with T. so that both quality and interpretation of the images were less than optimal. A report in the literature from one of the 27 B. C.D. D. P. Centers concluded that T. at its present stage of development had a limited role as a screening or pre-screening modality in stage I and minimal breast cancer.

B) RESULTS

This report is a review of the current results and T. findings from our Project at the Albert Einstein Medical Center. Gray tone images are recorded on 70 mm film utilizing the AGA 680 Medical Thermovision Unit. T. analysis and interpretation are based upon a slight modilication of the system in general use in the U.S. with emphasis upon pattern recognition. While it is roughly equivalent to the French classification of mammary T. wherein progressive degrees of abnormality are staged as TH1 through TH5 with THl and TH2 representing normal and benign conditions, TH4 and TH5 are significantly abnormal and TH3 being

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equivocal, our categories lack a reference to specific quantitative thermal differences of the 2 breasts. Asymmetry, whether graphic or thermal, is the key finding.

Of the 5,000 women screened, cancer was detected in 62 patients (12,4%); 4/62 patients had bilateral cancers, 3 of which were detected by mirror image biopsy of the unsuspected breast. T. was considered normal in 9/62 patients (14,5%) and of the remaining 85,5%, l0/62 (16,1%) were equivocal, corresponding to the TH3 category, and 43/62 (69,3%) definitely abnormal. Minimal cancers, defined as non-infiltrating or infiltrating under 1 cm in diameter, accounted for 20/62 (32%) of the cancer patients. While the numbers are small, it is apparent that the rate of suspect patients T. is no less with minimal cancers than with the total group and actually may be slightly higher, with 90% accounting for the abnormal and equivocal groups, and 10% for the normals (Tab. I).Surprisingly the 10 intra-ductal and 3 in-situ lobular cancers have a rate of abnormality similar to the total group of 20 minimal lesions. The significance of this is emphasized when one considers the frequent difficulty in clearly establishing a C.E. or M. diagnosis in these groups (Tab. II).

Utilizing axillary node evaluation for staging and prognosis reveals that 42/62 cancer patients (68%) were free of axillary metastases; 12/62 (19%) had l-3 nodes positive for metastasis while only 8/62 (13%) had involvement of more than 3 nodes. These figures tend to stress the early stages of the overwhelming majority of the patients (Tab. III).

Tab. I. **Thermography in** total **breast** Cancers (62 patients).

Thermography	Minimal* **20 (32%)**	>Minimal **42 (68%)**
Abnormal	15 (75%)	28 (67%)
Equivocal	3 (15%)	7 (17%)
Normal	2 (10%)	7 (16%)

* Non-infiltrating or infiltrating under 1 cm in diameter.

Tab. II. **Thermography in minimal cancers** (20 patients).

Thermography	Intra-ductal 10	«In situ» lobula **3**
Abnormal	7 (70%)	3
Equivocal	2 (20%)	-
Normal	1 (1 0%)	-

Tab. III. **Thermography in detecting aXil-** lary nodes (62 patients).

Thermography	Number of axillary nodes		
	>3	0	**I-3**
	8 (13%)	42 (68%)	12 (19%)
Abnormal	5 (62.5%)	28 (67%)	10 (83%)
Equivocal	1 (12.5%)	9 (21%)	–
Normal	2 (25%)	5 (12%)	2 (17%)

C) CONCLUSIONS

T. can play a significant role as a risk marker for minimal and early stage breast cancer. Training, perseverance and experience are required if expertise in T. interpretation is to be achieved. Prerequisites include technically satisfactory images and recognition of abnormal criteria. Among 5,000 self selected asymptomatic women, 62 patients with breast cancer were found, 85% of whom had abnormal or equivocal T. criteria.

Breast fibrocystic disease and thermography

by C.J. HUBER,[1] J.Y. PONS[2] and A. PATEAU[1]

[1] Gynecologic Clinics and [2] Department of Radiology, Hospital of Creteil, Paris (France)

Summary. Thermography (T.) is useful in breast benign disease to identify progesterone shortage and to control the effect of medical substitutive treatment. Results of a 4 yrs survey of 180 women with benign breast desease treated by progesterone are presented.

Key words: breast fibrocystic disease, thermography, progesterone, dysplasic B.

A) INTRODUCTION

In breast benign disease, due to progesterone insufficiency,4 one can distinguish: 1) **Elementary dysplasia,** with premenstrual breast pain extending over the whole cycle on a backward way, beginning in the upper outer quadrant of the left breast; becoming bilateral with breast congestion and without any palpable mass. **2) Organised dysplasia,** with structural changes in the breast, sensation of nodes and granulations, increasing in premenstrual period, seen in elder women (35-45) with former mastodynia. In these conditions, the following benign breast tumours are seen: a) ***adenoma*** for young girls with large development of glandular tissue; b) *cyst* in older women with tubular structure surrounded by sclerosis. Progesterone insufficiency makes the hormonal receptors able to receive more estrogen simulation, and then increase the metabolism in the breast.

B) MATERIAL AND METHODS

As thermography (T.) depends on breast metabolism and thermal vascular pattern depends on this metabolism, the Authors tried to show that: 1) T. demonstrates ***breast benign mastoputhiu;*** 2) changes in breast thermal pattern following treatment correspond to the ***improvement of breast trophicity.***

1. Benign mastopathia

There are actually 3 different classifications of breast vascular pattern: N.C.I.;[1] Strasbourg;[2] Marseilles.

Based on the Authors experience on more than 20,000 examinations, a subcategory of type B has been defined, called Dysplasic B.[3,6] It is usually symmetrical, sometimes only on one side at the beginning of the disease. This kind of type B is intermediary between the normal type B and the type D with some intricate vascular pattern in the upper quadrants of both breasts or with little vascular spots regularly scattered like wheel spokes (Fig. 1).

The dysplasic type B, together with the type D, which can be considered as an increasing of

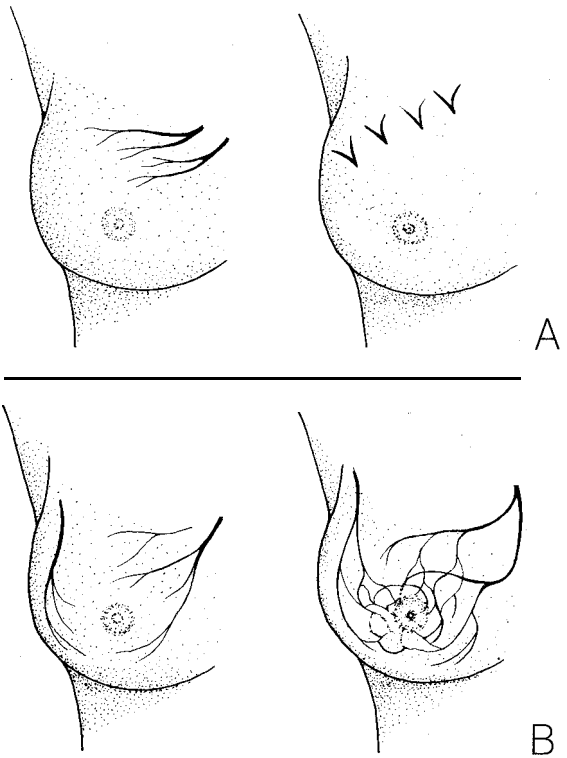

Fig. 1 A-B. Fibrocystic disease. A) Dysplasic B pattern. B) C-D or type III pattern.

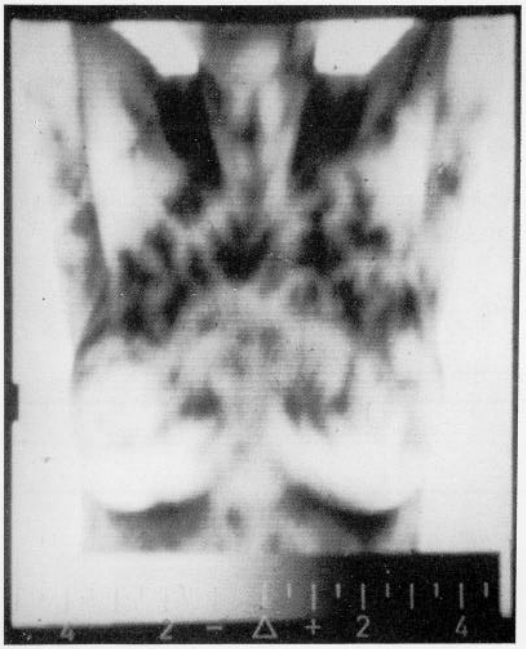

Fig. 2. Typical dysplasic B with Intricate vascular pattern in the upper quadrants. Progesterone insufficiency in plasmatic dosage.

the former one, are the most frequent benign diseases (Fig. 2).

In order to control the correlations between T. and breast dysplasia a dosage of plasmatic hormones was done. Progesterone and 17 β-oestradiol were measured in the second part of the cycle of 60 women with breast tibrocystic disease, and of 20 women without any symptoms.

The normal women essentially exhibit patterns of type A or B, with exception of women with large falling breasts associated with venous pathology visible by diaphanoscopy. More than 80% of the women with mastopathy exhibit a dysplasic B or D type. Some of them had asymmetrical pattern correlated with more important symptoms on this side or with more glandular tissue, as visualised by echography. Real hyper-oestrogenia gives also an important vascular pattern, as demonstrated by observations of a man using oestrogenic treatment or of a woman using it during the menopause.

2. Treatment follow-up[5]

In total 180 patients with mastodynia and fibrocystic disease, treated with percutaneous progesterone (PROGESTOGEL) and luteal hormones in the second part of the cycle (ORGAMETRIL), were examined (Tab. I and II). Clinical improvement with decrease of pain and nodes as well as changes of the vascular pattern is

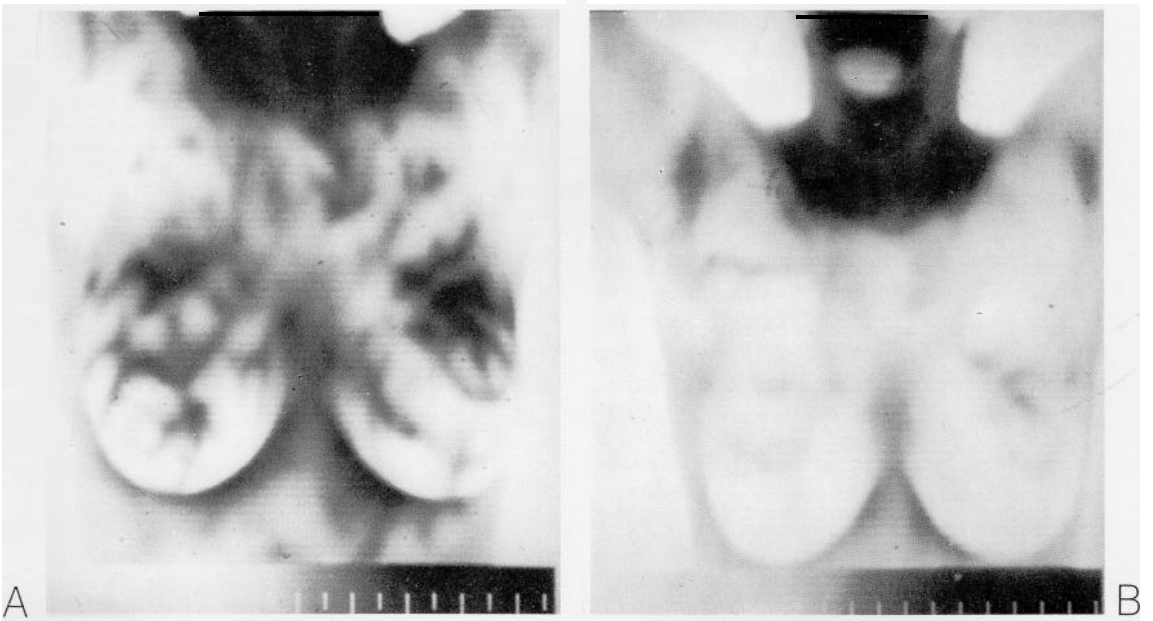

Fig. 3 A-B. A) Breast pain with nodes in both breast T. bilateral D. B) 6 months after progesterone treatment (oral and percutaneous). Important decrease of vascularity (A or B type).

Tab. I. **Results of the treatment** (180 women).

Follow-up	Mastodynia 59.5%	Organized mastopathia 40.5%
Clinical improvement	75.5%	85%
Unchanged	8.3%	3%
Worse	16 %	12%

especially in those women with a benign pathology but a normal thermovascular pattern who, usually, do not benefit of progestative therapy. The venous factors in benign pathology should be further investigated.

Actually, it is only the combination of different examinations that can give an answer to the questions in breast problems.

Tab. II. **Thermographic pattern modification after treatment.**

Type	Benian disease		Normal women
	Before	After 6 months treatment	
A	1%	10%	20%
B	4%	40%	50%
)ysplasic B	50%	20%	6%
C	3%	3%	2%
D	40%	25%	20%
E	2%	2%	2%

observed. The type D went back to B with decrease in intensity and extension, the same for dysplasic B. A lot of asymmetrical aspects became symmetrical (Fig. 3 A-B).

CI CONCLUSION

The T. picture reflects breast physiology in breast carcinoma as well as in breast benign disease. From the present study T appears to reflect benign pathology due to hormonal changes. T. helps in choice of treatment.

However, all possibility of T. for the evaluation of treatment of fibrocystic disease needs to be explored more completely. In fact, some interesting problems have to be solved,

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Comparison of telethermography and contact thermography in breast thermal examinations

by W.B. HOBBINS

Wisconsin Breast Cancer Detection Foundation, Inc., Madison (U.S.A.)

Summary. After comparison of 1,000 Telethermograms (T.) with Contact Thermograms (CT.), the equivalent information on T. is available on proper C.T. C.T. is more complete with absolute temperatures, sharper resolutions, excellent reproducibility and more accurate pattern magnification. Due to routine availability as an inexpensive process, T. now becomes a must for better surveillance of the health of the breast. It will subdivide all breast conditions into thermobiologically significant and insignificant classes.

Key words: telethermography, comparison, contact thermography.

A) INTRODUCTION

The study of the temperature of living things is becoming increasingly important - for understanding their Creation. Thermology of the body with its circadian thermal rhythms and its significance to health and disease is becoming a science of itself. The thermology of cancer and the growth of benign and malignant tumours and the sensitivity of these tissues to the increase or decrease of heat in the manifestations of its growth or decay is also becoming more significance. As a result, 2 methods have evolved for the study of the thermology of the breast through recording infra-red radiation. One being Telethermography (T.) using the electronic amplification and recording of imagery upon an oscilloscopic screen, and the other being the use of cholesteric crystals (Contact Thermography: C.T.) selected for various temperatures causing different refraction of reflected light resulting in specific temperature colours.

B) METHOD

In October of 1977 cholesteric plates became available for research study in the U.S.A. through Thermal Imagery, Inc., Dayton, Ohio. Upon receipt of this equipment a study of concomitant examinations of healthy and abnormal women's breasts was carried out with T. and C.T.

After an excellent experience with T. since 1972 (analysis of 43,000 examinations of the breast),[2] the approach to this comparative study was built in prejudice! The prejudice was that C.T. was probably extremely inferior to anything that might be obtained by a $40,000 machine that had electronics and all such other good things. However, 1000 female breasts were examined with both T. and C.T concurrently. In most regards C.T. was determined superior in information to that of T. (Tab. I). This statement must be qualified as there are some residual advantages of T. but they do not, in personal opinion, improve the accuracy of the thermal analysis of the physiology and pathology of the human breast.

C) COMPARISON

1. Equipment. The cholesteric system produced no mechanical failures. During the past 6 yrs there were 2 Spectotherm 1000 units. The down time during the present study of 9 months was 3 wks.

2. Resolution.The overall resolution was the sharpest on the C.T. examinations. The factors which made this so were as follows: a) the ***focus of the plate and camera*** are fixed in the cholesterics method. The variables with T. are failing relays, external adjustment of the machine by technician of contrast and brightness and photographic quality. In T. the optics from patient to machine are factor one; b) elec***tronics to oscilloscope; c) photography of scope.***

3. Reproductibility. The C.T. produced the most constant examination. As stated under the discussion of resolution it is apparent that the multiple variables in the equipment itself limit reproductibility. Further factors such as cooling and ambient conditions also effect more as far as reproductibility.

4. Technicians influence. Cholesteric plate selection by the technician is very important so that all the temperature information is recorded. Dr. M. GAUTHEERIE'S' only significant criticism of C.T. was his concern for the lost information/additional heat in the blue colour. This is now overcome by the Omega* Plate (6 colour plate). In T. the technical adjustment of the equipment is the most important factor. Critical review of T. exams will results in 20% being unsatisfactory for confident readings.

5. Temperature. With 6 colour cholesteric plates with ranges of 3°C (Alpha* Plates) or 6" C (Omega* Plates) absolute temperature to 0.1°C can be read. This has been confirmed previously by Dr. J. TRICOIRE.[6]

T. must depend on external calibration for absolute temperatures. However, black and white T. leaves information as to the amount of additional temperature in blacks and whites similar to the previous criticism of C.T. Colour helps overcome this but the addition of it electronically reduces resolution of the T. system.

6. Ambient conditions. C.T. was carried out in the controlled cooled environment in this study. The need of controlled environment for T. has been previously shown.[4] However, it has been stated that this is not necessary for C.T. and this has been confirmed in this study as well. This would mean that satisfactory C.T. can be carried out in the ordinary physician's office, a distinct advantage.

7. Range Of temperature. No difference in the range of temperatures observed and recorded was noted in this study.

* Thermal Imagery, Inc., Dayton, Ohio (U.S.A.)

8. Content. T. produces a thermascape [4] of the breasts. This allows easy comparison of one breast with another. In addition there is included a reference point for whatever significance it is over all. C.T. includes only the portion of the breast that is compressed to the applied plane. Because of the nature of breast substance the amount of information included in each view is the same for the most part when compared to T.

9. Positioning. An advantage of C.T. is its great accessibility to the configuration of a given breast. In the a. p. projection the nipple can be centered in the plate so that the important portion of breast thermology observation can be properly evaluated. And in the lateral view the nipple system can be placed on the edge of the plate centered midway again giving the information in full and complete relationship. Often times with most breasts the necessity of table examination where the same flattening of the breast can occur, should be done but is not done with T. The nipple being on the inferior portion of the frontal projection in the standing or sitting position much information is lost which with C.T., was extremely significant.

T. using the standing or sitting position with arms raised loses much sub-areolar information obtained by plates but includes in some cases better medial information. In order to obtain information similar to C.T. with T. a patient must be placed supine on a table for flattening of the breast.

Concern that a flat surface against an ovoid body such as the breast could record the information accurately or record the information at all, was an original concern. It became apparent in this study that as the breast is flattened as a result of centering of the nipple and compressing the breast against the flat plate, most infra-red rays are then in a parallel direction. These rays then disturb the crystals which are then observed by the refraction of lights which are specifically projected at 45". The accuracy of this information is phenomenal. In this regard the difference between a cholesteric plate thermal picture and the amplified open thermal plate picture is not only theoretically better, but in actuality is far superior.

Tab. I. **Technical comparison between telethermography and contact thermography.**

	Telethermoaraphv	Contact thermoaraohv
Equipment failure	occasionally	none
Resolution	less sharp	sharp
Focus	variable	constant
Reproductibility	variable	fixed
Technicians influence	important	less important
Temperature	calibrated	absolute
Controlled ambient conditions	necessary	unnecessary
Range of temperature	satisfactory	satisfactory
Content	broad	localized
Reference point	present	absent
Positioning	complicated	easy
Edge sign	present	present
cost	high	low

10. Fidelity of anatomical reproduction. In the patients examined the edge signs presented were seen in all cases by both methods. The thermal content of the area was better demonstrated by the plates however.

Interestingly, in many cases the cholesterics by the use of accurate temperatures of the area of the edge sign did increase the information from such deformities.' Scars of the breast are also much more easily discerned from significant edge signs from underlying tumours or disease that causes subtle retractions. Edge signs are often seen when physical exam does not reveal this distortion. C.T. is more reliable for demonstration of the vascular tree, showing anarchy, moa-moa, hot spots and vascular pecluncles better.

11. Cost. C.T. equipment is significantly less expensive than T. eqipment. In addition, no expense for ambient temperature control is necessary with C.T. and the maintenance of the equipment is insignificant. Break down time and repair expense must also be considered.

D) CONCLUSION

Present study would confirm the findings of GAUTHERIE' and HUBERT that C.T. does record the heat demonstrated by T. very well. C.T. records with accurate resolution the thermal process and a most accurate temperature measurement (using newly designed 6 colour plates) when compared with that of T. Any theoretical disadvantages when analysed in the clinical arena did not arise. It should be noted, however, that the individual interpretation of the T. was less accurate using either method separately. A comparison of both methods in each individual case gave a higher level of confidence than was reached previously with a single method.

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Elc contact thermography

by K.A. SHAFFER,① J.R. MILBRATH,① M. MOSKOWITZ,② S. FOX,② R. GOLD② and L.W. BASSETT③

① Medical College of Wisconsin, Milwaukee; ② University of Cincinnati; ③ UCLA Center for Health Sciences, Los Angeles (U.S.A.)

Summary. Three centers in the U.S.A. are prospectively studying contact thermography (C.T.) to determine whether this type of T. can detect women with proliferative mastopathy (including carcinoma); 500 women who are scheduled for breast biopsy and 1500 control women with normal mammograms and clinical examinations will be studied. All T. will be independently interpreted by a physician who will not know results of physical or X-ray examination.

Key words: contact thermography, masthopathy, breast cancer.

A) INTRODUCTION

Three academic Centers in the U.S.A. are conducting a 1 yr study to determine whether liquid crystal thermography (C.T.) can detect patients who have breast cancer or significant premalignant mastopathy, and whether it can do so at a rate greater than chance alone in an asymptomatic population of women. These centers are: The Medical College of Wisconsin, The University of Cincinnati, and The University of California at Los Angeles. T. has been proposed as a safe, painless, noninvasive, totally innocuous procedure to detect patients with breast cancer. Critical review of previously published data, and objective studies performed to date have failed to substantiate that highly curable, small malignancies' can be detected by tele-T.

1. A relatively **new type of T. (C.T.)** has become available for clinical evaluation. This method of T. is a contact method of measuring temperature emission from the surface of the breast. In the system being evaluated, microencapsulated crystals of liquid cholesterol ester are sprayed in a thin uniform coating on one side of a black Mylar sheet. This semiflexible plastic sheet is attached to a frame, producing a plate. This plate is placed directly on the skin, with the crystal side away from the patient. The crystals change colour in response to surface temperature, and the image is recorded on 35 mm colour film. The image disappears rapidly when the plate is removed from the breast. The plates have thresholds of temperature sensitivity varying from 31 to 34°C. Each plate has a 3°C range, so that the highest temperature visible is 37°C. By using the appropriate temperature plate, the heat emission of the breast can be semi-quantified by the colour changes. Subjective colour changes occur with temperature changes of the order of 0.15°C. The colours on the plate progress from reddish-brown through light green, dark green and blue, with the upper limit of the plate a violet colour.

It has been claimed by TRICOIRE and others that C.T. is highly sensitive for detection of carcinomas, even small ones, and it is relatively specific for that diagnosis. However, the work of other investigators shows great variation in the sensitivity and specificity of C.T. The work of BRUN DEL RE would suggest that, while C.T. is insensitive for detecting small cancers, it has potential value to identify women with proliferative mastopathy. While many published series indicate that C.T. may be more sensitive than tele-T., both methods appear to be relatively insensitive in patients with small carcinomas.

2. For the purpose of this study, **proliferative mastopathy** shall include invasive cancers and those pathologic conditions which have been reasonably demonstrated to increase the patient's risk for developing subsequent invasive carcinoma. These conditions include intra-ductal carcinoma; in situ lobular carcinoma; lobular hyperplasia, with or without atypia; and ductal

hyperplasia, either papillary or non-papillary, atypical or non-atypical. Based on the experience of MosKowITz and a review of the literature, fibroadenomas which are non-involuting and non-hyalinized developing in women over the age of 40 are included in this definition of mastopathy. It will be not considered as part of proliferative mastopathy or proliferative breast disease the diagnoses of simple fibrosis, cyst formation, apocrine metaplasia, fat necrosis, or other granulomatous changes in the breast. Further, there will be not considered a clinical diagnosis of mastopathy as having any meaningful significance. The clinical diagnosis of mastopathy includes lumps, mastodynia, nipple discharge, bleeding, etc. These are all clinical signs which can be seen in both proliferative and non-proliferative breast disease. Therefore, in order to determine the accuracy of T., it will be necessary to compare positive interpretations of C.T. with biopsy diagnoses.

B) METHOD

All women coming to surgical biopsy for suspected breast lesions will be examined; 500 women will be in this pre-biopsy category, and about 20% of these- will have carcinomas. Probably a third of the benign lesions biopsied will contain pathologic findings of proliferative breast disease.

All 1500 women who have completed their screening examinations at the Milwaukee and Cincinnati Breast Cancer Detection Centers will also have C.T. performed. Women will be chosen who have been considered essentially normal by all modalities on the current examination, and on the preceding annual examination.

The T. unit consists of a frame which holds both the plate and camera. The plate can be easily changed, and the skin temperature of the individual patient determines which plate is used. A marker near the plate can be adjusted to identify each view. The unit is lightweight and is usually removed from the supporting stand for use. The supporting stand also holds the air blower, which is used to cool the breasts. The entire unit is compact and easily moved. Trained radiologic technologists will perform C.T. of both breasts in the AP and oblique projections. Four pictures are taken of the images before cooling. Then, using the air blower, the breasts are cooled briefly, and the same views are repeated. These 2 images are oblique views before cooling. The patient identification and view markers are easily seen. The left axilla is warmer than the right one and there are more vessels; this area appears bright blue. The central portions of both breasts around the nipples are cool, with a reddish-brown colour. Following brief cooling with the blower, both breasts have changed considerably in temperature. The post-cooling films are done as soon as the nipple image reappears on the plate. This will standardize the time at which these images are taken. It may become desirable to do an additional AP and oblique image of each breast with infra-red film. This will give the course and position of the superficial veins. This aspect of the study will be explored further, and if it is feasible and cost-effective, it may be added subsequently. All images will be identified by an accession number of the cooperating Institution, and the films will be forwarded along with background data on the patient to the image processing Laboratory of the University of Cincinnati Medical Center. The images of the screened patients will be sent to Cincinnati as soon as they are done. The images of the pre-biopsy patients will be held until the biopsy report is obtained, and the images will then be forwarded along with the biopsy report. The image processing Laboratory will extract the appropriate pathologic data onto a computer form for data analysis.

A reasonable mix of biopsied and screened patients will then be assembled and forwarded to Dr. **Brun Del Re** in Basel, Switzerland, who will be requested to interpret the images. He will not know the physical examination or x-ray findings. He currently uses 5 categories for interpretation: A is normal, B represents a benign abnormality, but early follow-up is recommended, C- is mildly suspicious, C+ represents significant premalignant mastopathy, and D is obvious malignancy. For purposes of categorizing the significance of a given lesion, all patients diagnosed as A, B, or C- will be considered normal. Patients categorized as C+ and D will be considered abnormal.

At this time, the study can only be expected to give meaningful information on the true

positive identification rate of proliferative mastopathy by C.T. compared with the positive rate found in asymptomatic screenees. Authors will not be able to determine the meaning of a negative T. from this short-term study. If CT. identifies an acceptable percentage of patients with proliferative disorders and there is a relatively low positive rate in asymptomatic women, one should identify patients harboring cancer or proliferative disorders of the breast at a rate greater than chance alone using C.T.

It would be possible to gain a reasonable approximation of the false negative rate by extending the follow-up period of this study over an interval of 3 yrs, and by increasing the number of screenees examined to 2500. It is estimated that the risk for developing carcinoma of the breast in a patient with a proliferative disorder is 5 to 8 times greater than the risk of the general population. Thus, we should be able to tell within a period of 3 yrs whether there are patients with proliferative disease of the breast in the population of asymptomatic women who have negative T.

Cholesteric plate thermography: standardization and accuracy

by E.E. KOOPMAN

Thermal imagery,* Inc., Miamisburg, Ohio (U.S.A.)

Summary. Newer cholesteric formulations and improved encapsulation techniques have added a fourth contrast band and accompanying isotherm to the «Standard» Thermographic Cholesteric Plate (T.C.P.) series. The disadvantage of a limited thermal benchmark in the blue contrast band of the standard T.C.P. has been overcome by the addition of 3 higher temperature contrast bands in the «Omega» T.C.P. series. A third T.C.P. series, «Sigma», has been innovated to utilize the thermal differentiation presented by the Omega T.C.P. series, but with increased thermal sensitivity. The 3 series of T.C.P. have been calibrated to visually yield thermal data routinely to 0.2%

Key words: cholesteric plate, contact thermography, skin temperature, liquid crystal, cholesteric analysis profile (CAP).

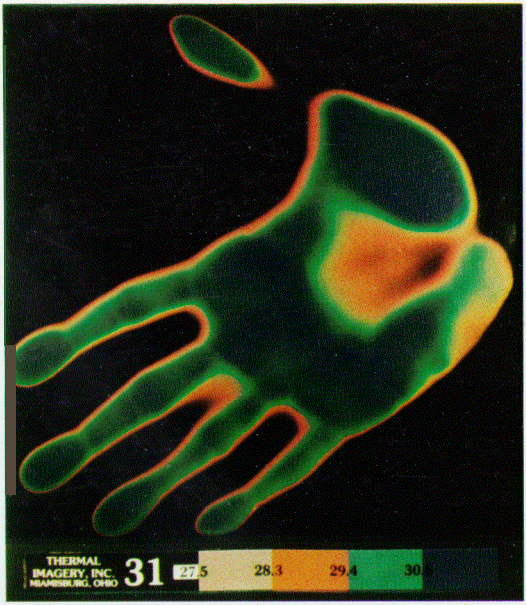
A) INTRODUCTION

The first widely reported use of sheets of encapsulated cholesterics for thermal medical investigations was published in 1974.[3] The latter part of this decade has seen intensive development activities to produce accurate thermographic plate cholesterics for the medical community.[4] To date, 3 general series of thermographic cholesteric plates (T. C.P.) have been manufactured in one form or another.

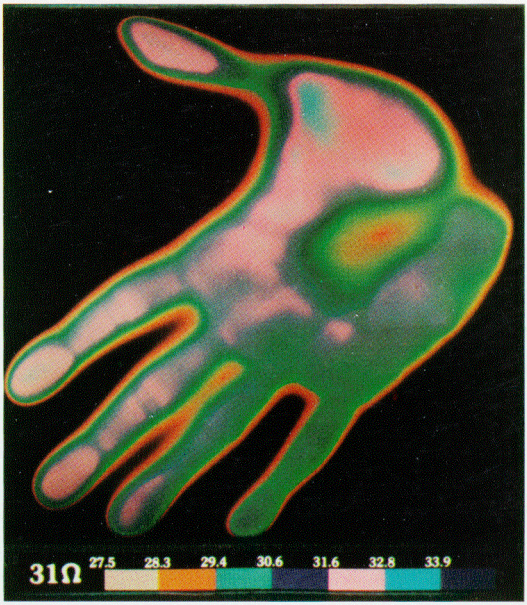
1. The first series of T. C.P. was an European innovation, now known as the **Standard T.C.P. series.** This series consists of 5 T.C.P. 's designated as 31", 32", 33", 34" and 35°C. Originally, only the contrast bands of red, green and blue were usable for a thermal determination. With the advent of newer formulations and encapsulation techniques, a fourth contrast band became usable. This band, which a physicist would call the second ***order reflection*** is now designated as the ***alpha order.***

The thermal window of each individual standard T.C.P. is some 3°C wide, i.e. from

* Officially, for the U.S.A., changed to VECTRA CORPORATION.



A



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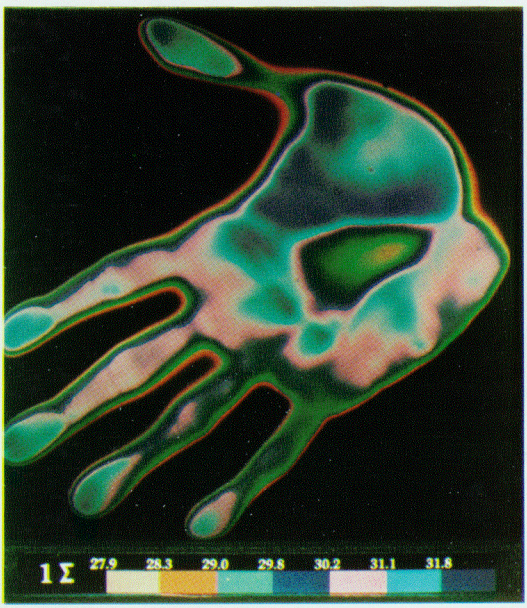


C

Fig. 1 A-B-C. Comparison of thermal presentation of Standard (A), omega (B) and sigma(C) T. C. P. (The subject was artificially heated to demonstrate thermal range; cross comparison of temperature is not possible).

the beginning of the alpha order to the beginning blue colour a 3°C temperature span can be recorded. The standard T.C.P. has been found adequate for many thermal determinations, but it does have the disadvantage that an individual plate has a limited thermal benchmark at its blue contrast band. No thermal data is available from the blue area. Fig. 1A is an example of the thermal response of a standard T.C.P. and illustrates the upper limit of a thermal determination at the green to blue isotherm.

2. **The omega T.C.P. series** was conceived and constructed to overcome this limitation of thermal differentiation in the blue band of the standard T.C.P. series. Three higher temperature contrast bands with their accompanying 3 isotherms were added. The total number of contrast bands, including alpha, in the omega T.C.P. series is 7. In order to clarify the exact thermal range presented by this newer series, an arbitrary, but hopefully, logical nomenclature has been assigned to the contrast bands. The second order reflection is assigned the therm ***alpha order.*** The red, green and blue is called the ***beta*** order(beta red, beta green, beta blue) and the added contrast bands, the ***gamma order.*** The gamma red can be described as magenta in colour, gamma green as an aqua and the gamma blue, as dark blue. The thermal events and windows of alpha and beta orders are the same as those found in the standard series, however, the total window of the omega T.C.P. is essentially doubled by the addition of the ***gamma order.*** Fig. 1B demon-

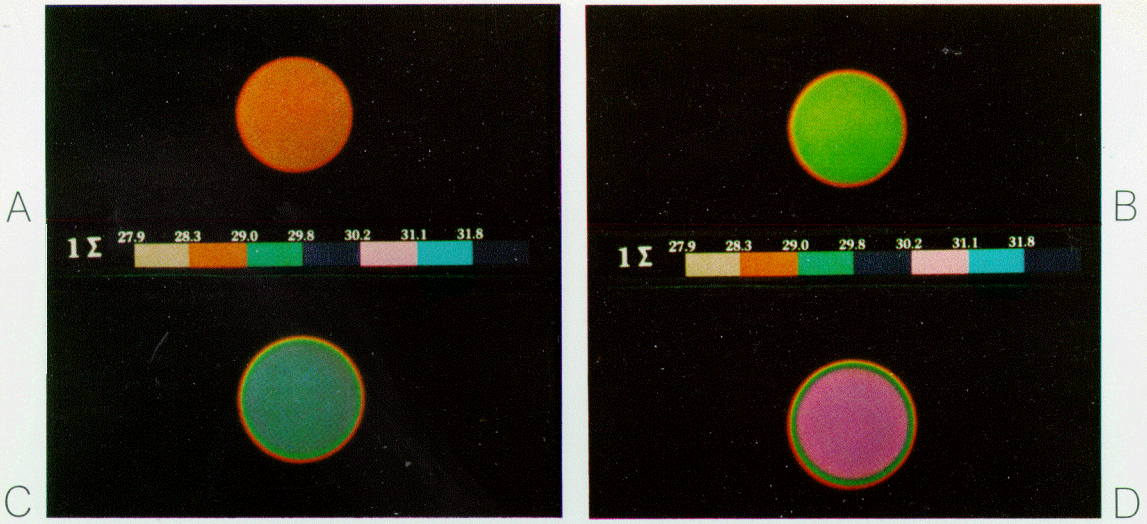


Fig. 2. Calibration colour-temperature response adjacent to the colour boundary between beta red-beta green (A-B) and beta blue-gamma red (C-D) (0.2°C interval).

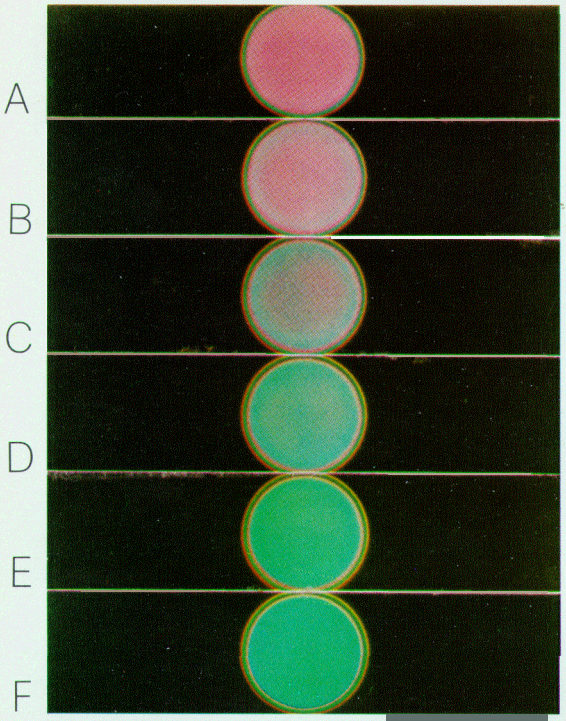


Fig. 3. Calibration colour-temperature response at 0.1° intervals across the gamma red-gamma green boundary. A) 29.9°C; B) 31.0°C; C) 31.1°C; D) 31.2°C; E) 31.3°C; F 31.4°C.

strates the thermal response of an omega T.C.P. and clearly shows thermal differentiation in those areas which would be blue in the standard T.C.P.

3. The next step in the evolution of T.C.P. was the concept and production of the **sigma T.C.P. series.** This series was innovated to utilize the thermal differentiations exhibited by the omega series and to increase the thermal sensitivity. This was achieved by having the same number of contrast bands but in a narrower window, i.e. more contrast band in a given thermal span, thereby achieving greater sensitivity or thermal resolution. Fig. 1C is an example of the sigma series.

When the use of T.C.P. is contemplated for obtaining a medical thermal determination, it is imperative that the user realize that the T.C.P. is just one part of a **system.** This system consists of the T.C.P., an illumination source, a camera-recorder, and photographic film. The resulting colour-temperature picture recorded by the system is directly dependent upon the angular geometry of these various components of the system, i.e., the wave length of light recorded varies with the incident light direction and observation angle.[1, 2]

B) THERMAL CALIBRATION

Accordingly, it is of the utmost importance that the system as a whole must be thermally calibrated to obtain an accurate isotherm-colour

temperature relationship. This calibration is obtained using incremented isothermal conditions. The system is placed against a 38 mm diameter copper test cell, which has a uniform thermal cross section. Photographic recordings are made covering the entire thermal range of the T.C.P. An electronic thermometer (Y.S.1. model 777, readability to 0.003°C, precision and accuracy traceable to N.B.S.) is used to record the temperature of each increment to 0.1°C. The pictures in Figs. 2 and 3 depict a portion of a calibration series of a T.C.P.

Once the thermal calibration of the system (plates plus fixed photographic geometry) has been established, color-matched calibration strips with the proper associate thermal data can be affixed to the T.C.P. The calibration strip can be seen in the lower portions of each picture in Figs. 1, 2, 3, and 4.

C) CHOICE OF T.C.P.

An individual T.C. P. has a finite thermal range or «window» to which it will respond, as can be seen in Tab. I. Thermal data can be obtained so long as the temperatures involved are within the response range of a particular T.C.P. There is, however, from a practical point of view, an optimum choice from each T.C.P. series that should be selected for ease of visualization and data collection. This choice, selected by trial, should result in a photograph having a preponderance of beta-red and beta-green with varying minimal areas of cooler alpha-order colour. Areas of higher temperature will be perceived as beta-blue with the standard plate or in the case of the omega and sigma plates, higher temperatures will be seen with the presentation of the gamma order of colours. In Fig. 4 the standard T.C.P., the 33 omega T. C. P. and the 4 sigma T. C. P. are

Tab. 1 **MS-100 cholesteric Plate calibration data T"C**

STANDARD	31	27.5	28.3	29.4	30.6	—	—	—
	32	28.8	29.6	30.7	31.9	—	—	—
	33	29.9	30.8	31.9	33.5		-	—
	34	31.2	32.1	33.2	34.5		-	—
	35	32.2	33.0	34.1	35.3		-	—
Ω OMEGA	31	27.5	28.3	29.4	30.6	31.6	32.8	33.9
	32	28.8	29.6	30.7	31.9	33.4	34.4	35.7
	33	29.9	30.8	31.9	33.5	34.1	35.3	36.4
	34	31.2	32.1	33.2	34.5	34.8	35.8	36.9
	35	32.2	33.0	34.1	35.3	35.6	36.5	37.7
Σ SIGMA	1	27.9	28.3	29.0	29.8	30.2	31.1	31.8
	2	29.0	29.5	30.2	31.0	31.3	32.1	32.9
	3	30.0	30.4	31.3	32.1	32.3	33.1	33.9
	4	30.9	31.3	32.2	32.9	33.2	34.2	34.9
	5	31.6	32.1	32.9	33.7	34.2	35.1	36.0

Temperatures refer to the boundary between 2 adjacent colours, which is an isotherm

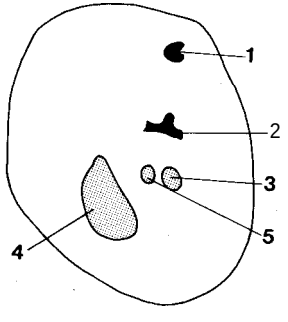
Tab. II. **Selected area thermal data (T°C).**

	Plate No		Standard		Omega		Sigma	
Area 1	31	1	>30.6	-	33.9	-0.2	>31.8	
	32	2	>31.9	-	33.9	-0.2	>32.9	-
	33	3	>33.5	-	34.1	o.o*	33.8	-0.3
	34	4	33.9	-0.2	34.0	-0.1	33.8	-0.3
	35	5	34.1	0.0	34.1	0.0	33.9	-0.2
Area 2	31	1	>30.6		>33.9	->31.8		
	32	2	>31.9		35.1	+0.1	>32.9	-
	33	3	>33.5	-	35.0	o.o*	>33.9	-
	34	4	>34.5	-	34.9	-0.1	34.9	-0.1
	35	5	35.3	+0.3	35.0	0.0	34.9	-0.1
Area 3	31	1	30.5	-0.7	31 .I	-0.1	31.2	0.0
	32	2	31.1	-0.1	31.3	+0.1	31.2	0.0
	33	3	31.2	0.0	31.2	o.o*	31,4	+0.2
	34	4	31.3	+0.1	31.3	+0.1	31.1	-0.1
	35	5	<32.2	-<32.2	-	<31.6		-
Area 4	31	1	30.4	-0.2	30.6	0.0	30.7	+0.1
	32	2	30.7	+0.1	30.6	0.0	30.6	0.0
	33	3	30.6	0.0	30.6	o.o*	30.5	-0.1
	34	4	<31.2	-	<31.2	-	<30.9	-
	35	5	<32.2	X32.2	X31.6			-
Area 5	31	1	>30.6	->33.8	->31 .a			-
	32	2	>31.9		34.2	0.0	>32.9	-
	33	3	>33.5	-34.2	o.o*	33.8		-0.4
	34	4	34.0	-0.2	34.2	0.0	34.0	-0.2
	35	5	34.2	0.0	33.9	-0.3	33.9	-0.3

*33 OMEGA designated as base temperature for convenience of comparison,

KEY TO AREAS

(From Fig. 4)



considered to be optimum presentation. The pictures to the left of each of these presentations are considered to be an «overdrive» display, i.e., temperatures are too high for optimal display; pictures to the right of the optimum presentations are an «underdrive» display.

D) REPRODUCIBILITY OF THERMAL PICTURE

The usefulness of T.C.P. for medical ther-

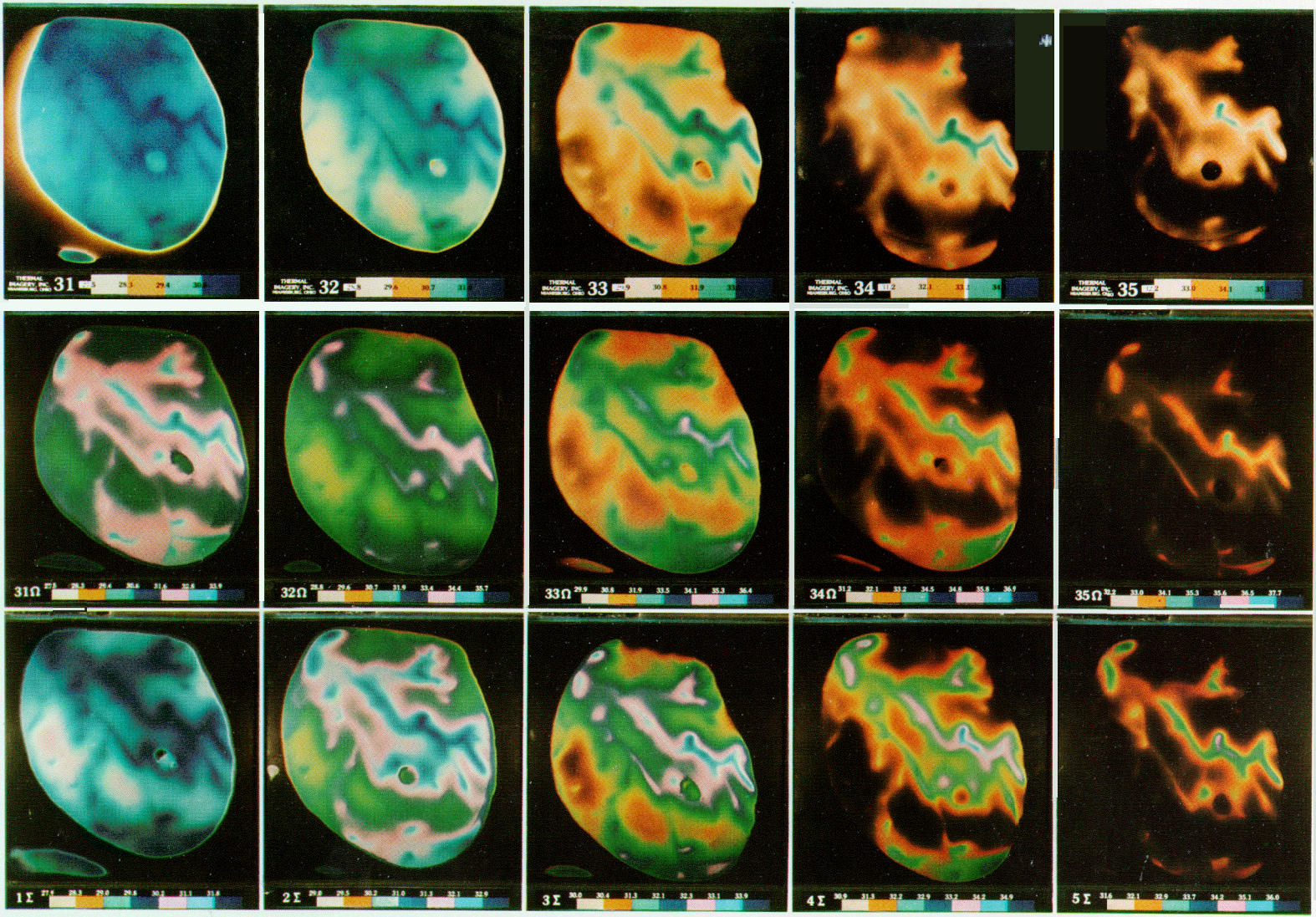


Fig. 4. Compilation of thermal presentations exhibited by the 3 series of cholesteric plates. Optimum pictures for this particular subject are 33 standard, 33 omega and 4 sigma.

ma1 determinations depends upon pattern reproducibility from plate to plate and series to series, which can be appreciated from Fig. 4, but more importantly upon the precision of thermal response and calibration.

Tab. II summarizes the thermal data for 5 selected areas, derived from the ***original*** photographs depicted in Fig. 4. The first column under each heading is the temperature determined for the area using a specific plate. The second column is the variance of the determined temperature with respect to the temperature measured by use of the 33 omega T.C.P. (no emphasis should be attributed to the 33 omega T. C.P.; it is an optimum T. C.P. and is conveniently located in 'the center of Fig. 4). Where the temperature of an area is greater than (>) or less than (<) the response range of a particular T.C.P., the appropriate indication has been made.

Excellent thermal correlation can be seen not only with respect to an individual T.C.P., but also intra-series as well as inter-series. The thermal differential (dT), warm (area 3) minus cool (area 4), is estimated to be 4.7°C for the standard T.C.P. series and is measured as 4.4°C and 4.3% for the Omega and Sigma T.C.P. series, respectively.

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Studies on biological effects of rotating magnetic fields by means of intra-red thermography

by K. ATSUMI, I. FUJIMASA, K. IMACHI, H. MIYAKE and A. KOUNO

Institute of Medical Electronics, Faculty of Medicine, University of Tokyo, Tokyo (Japan)

A) INTRODUCTION

Magnetic field has been considered to bring good results for health and many kinds of instruments to generate static magnetic fields have been produced and utilized in Japan. However, biological effects of magnetic fields were not approved on details by scientific methods. Therefore, special designed instrument of rotating magnetic field generator was constructed by Authors and the biological effects - in particular thermal effects - were investigated utilizing the method of infra-red thermography (T.).

B) METHOD

The scheme of the instruments of rotating magnetic generator is shown in Fig. 1. DC motor rotates the disk of the top where 2 tips of Samalium-Cobalts (400 G, 1000 G, 3200 G) are installed. By motor driving, rotating magnetic fields can be produced (Fig. 2). It is considered that pulsatile magnetic fields are generated by rotation of motor.

1. Measurement of thermal effects of the instruments. In the first experiment, 2 kinds of instruments were constructed, 400 and

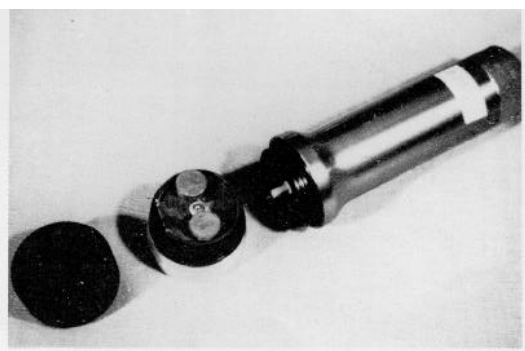


Fig. I. Rotating magnetic generator. From left: cap, 2 tips of magnetics (Samalium Cobalt etc.) and motor.

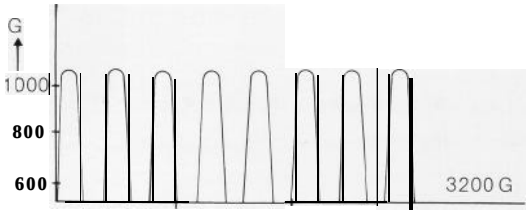
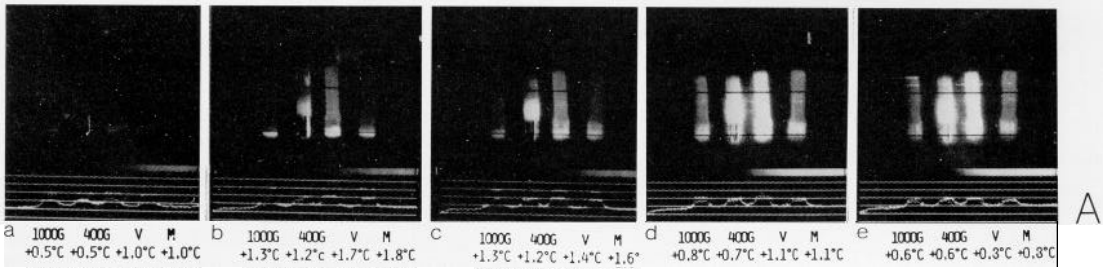


Fig. 2. Change *of magnetic denszty during driving of generator*. Pulsatile magnetic fields can be generated by rotation of motor.

rator for 5 mins (Fig. 4). T. were taken before stimulation and 0, 1,5,10,15,20 mins after stimulation respectively. As the control, another symmetrical side was stimulated by vibration and their T. were also taken. The serial changes of these digital temperature data were compared and analyzed (Fig. 5).

3. Effects of rotating magnetic generator for the patients. Effects of rotating magnetic generator were detected for 75 patients by T. Pathological regions were stimulated by rotating magnetic generator for 5 min. T. were taken before stimulation, and 0, 1,5,10, 15 mins after stimulation respectively. As the control, T. of another symmetrical side were taken in series respectively. The serial change of these digital temperature data were compared and analyzed.



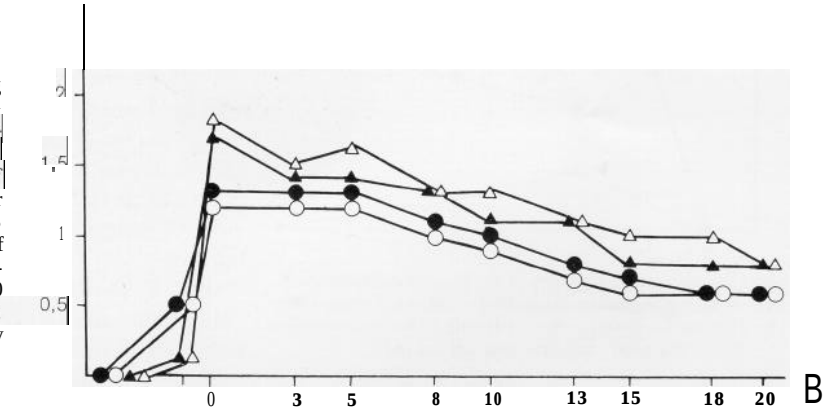


Fig. 3 A-B. A) T. of 2 rotating magnetic generators (400 G and 1000 G) vibration instrument (V) and motor (M) in room temperature. a: stop of stimulation; b: 2.5 mins after stimulation; c: 5 mins; d: 13 mins; e: 20 mins. B) Curves of temperature changes of rotating magnetic generators (400 G = ○ 1000 G = ●), vibration instrument (A) and motor only (△).

1000 G of magnetic power. As control use, instruments of vibration only and motor only that are same size and shape as the magnetic generator were constructed and their biological effects were compared. After 5 mins driving of these instruments simultaneously, the changes of T. in room temperature were detected (Fig. 3).

2. Effects of rotating magnetic ge- C) RESULT
nerator for healthy subjects. Effects of rotating magnetic generator were detected for 20 healthy subiects by the method of T. Face. back, forearm, legs ktc. of healthy subjects were stimulated by rotating magnetic gene-

1. Measurement of thermal effeCtS of instrument

Fig. 3A shows the T. of the serial temperature changes of rotating magnetic ge-

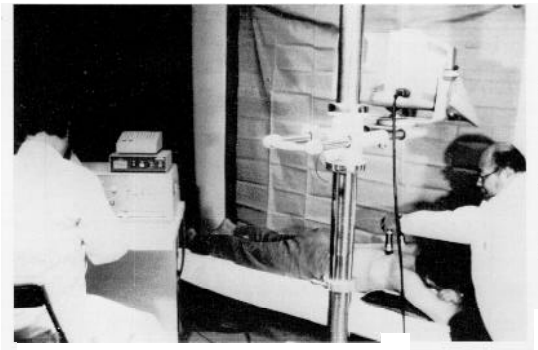


Fig. 4. T. taken during stimulatlon by rotating magnetic generator and control (motor, vibration) on the back of a healthy subject.

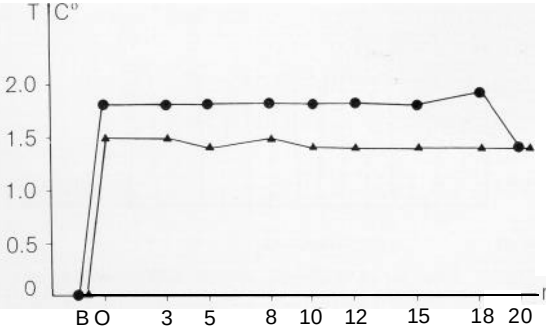


Fig. 6. Temperature changes of the back of a healthy subJect. Rotating magnetic stimulation (1000 G, 5 mins = 0). The control is referred to the other side of the back stimulated with vibration instrument (A),

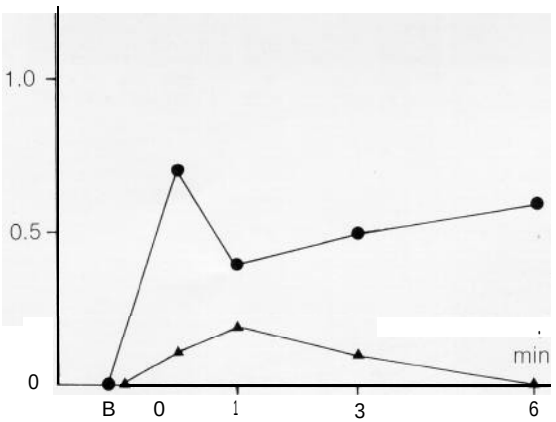


Fig. 5. Temperature changes of the face of a healthy subject. Rotating magnetic stimulation (1000 G, 5 mins = ●). The control is referred to the other side of the face stimulated with vibration instrument (A).

nerator (400 G and 1000 G), instruments of vibration and motor only. The curve of serial changes of digital temperature is shown in Fig. 3B. These temperature changes show the same trends and rather higher in temperatures of vibration and motor only compared with those of rotating magnetic generators. Namely, the higher thermal effect of magnetic generator itself is not approved compared with those of vibration and motor only.

2. Effect of rotating magnetic generator for healthy subjects.

Fig. 5 shows the thermal changes of 1000 G and control of vibration only on healthy face in the curves of temperature change. Temperature of the region of 1000 G stimulation is shown higher than that of vibration only.

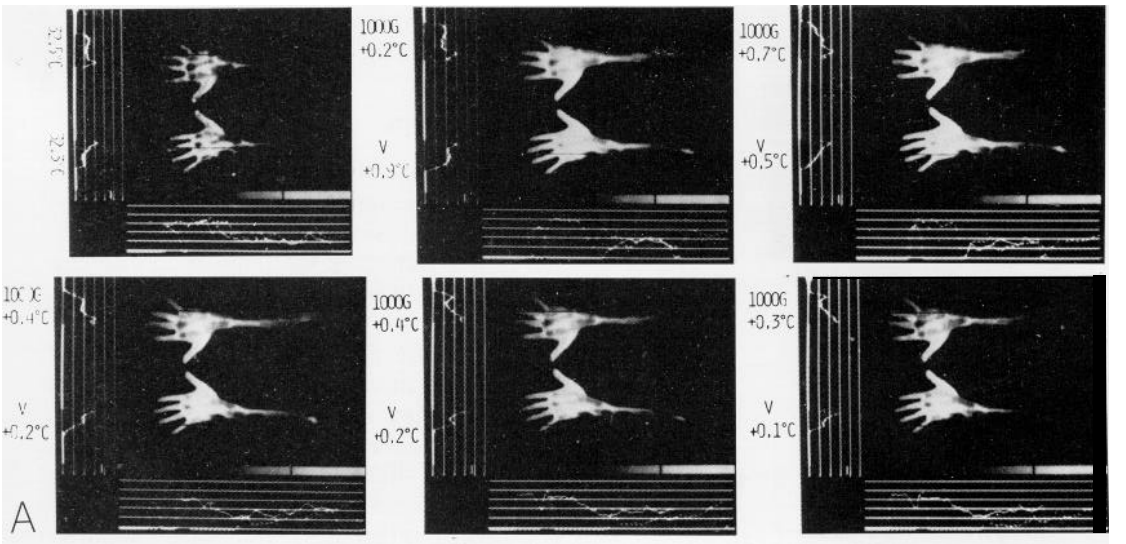
Fig. 6 shows the thermal changes of magnetic stimulation effects on healthy back for 20 mins; the higher temperature of the region stimulated by 1000 G is maintained until 18 mins compared with those of the control region. Fig. 7A shows the T. of magnetic stimulation on healthy forearm. Fig. 7B shows that the temperature curves cross after several mins and then, the higher temperature of the region of 1000 G stimulation is maintained even 20 mins after stop of stimulation compared with those of control.

Fig. 8 shows the temperature changes of magnetic stimulation on healthy legs; there is higher temperature of the region of 1000 G stimulation continued until 15 mins after the stop of stimulation, compared with those of control.

3. Effect of rotating magnetic generator for the patients

Three thousand two hundred G. of magnetic power of rotating magnetic generator was newly constructed and 2 kinds of 1000 G and 3200 G of the instruments were applied for 75 patients.

Fig. 9 shows the T. results on the patients of right gonitis. Right patella was stimulated by 1000 G for 5 mins; there is higher temperature of the region of 1000 G stimulation- than that of contro1 of another side. Fig. 10A shows the T. of the results on the patient of omo-arthritis. Left posterior



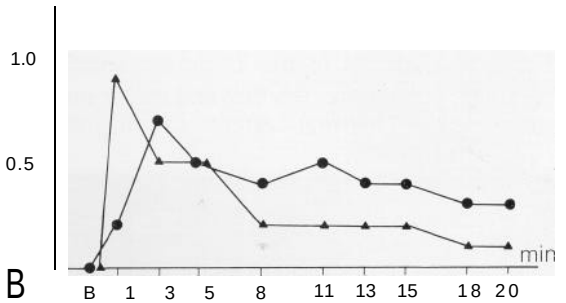


Fig. 7 A-B. A) T. of the forearm of a healthy subject, by rotating magnetic stimulation (1000 G, 5 mins). The control is referred to the other forearm stimulated with vibration instrument. a: before stimulation; b: 1 min after stimulation; c: 3 mins; d: 8 mins; e: 15 mins; f: 20 mins. B) T. changes of the forearm of a healthy subject.

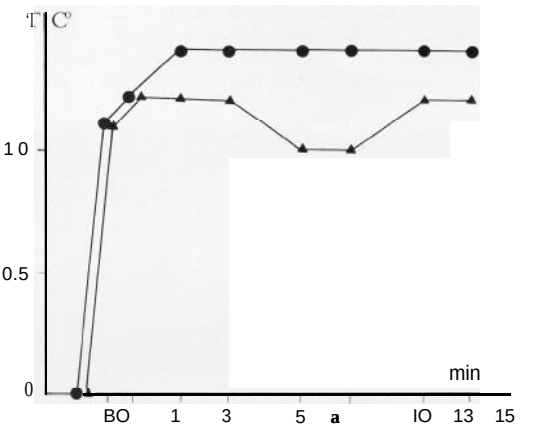


Fig. 8. Temperature changes of the leg of a healthy subject. Rotating magnetic stimulation (1000 G, 5 mins = ●). The control is referred to the other leg stimulated with vibration instrument (A).

neck was stimulated by 3200 G for 5 mins. Fig. 10B shows higher temperature of 3200 G than that of another side for 10 mins after stop of stimulation.

Fig. 11 shows the temperature changes on a patient with knocked knee. Right patella was stimulated by 3200 G for 5 mins; the higher temperature of 3200 G than that of another control side is maintained until 10 mins. Fig. 12 shows the temperature changes on upper limb neuritis.

Right supra-scapular region was stimulated by 3200 G for 5 mins.; there is higher temperature of 3200 G than that of another control side is maintained even 10 mins after stop of stimulation.

Tab. I shows the thermal effects of rotating magnetic fields on 16 clinical cases. Thermal effects are classified as follows: +++: higher temperature more than 1°C; ++: higher temperature more than 0.5°C; +: higher temperature more than 0.3°C; ±: higher temperature more than 0.1–0.2°C.

The thermal effects - increase of temperature on the surface of stimulating regions - were detected and subjective improvements of patients were approved.

In 16 cases of patients, 3 cases of +++, 3

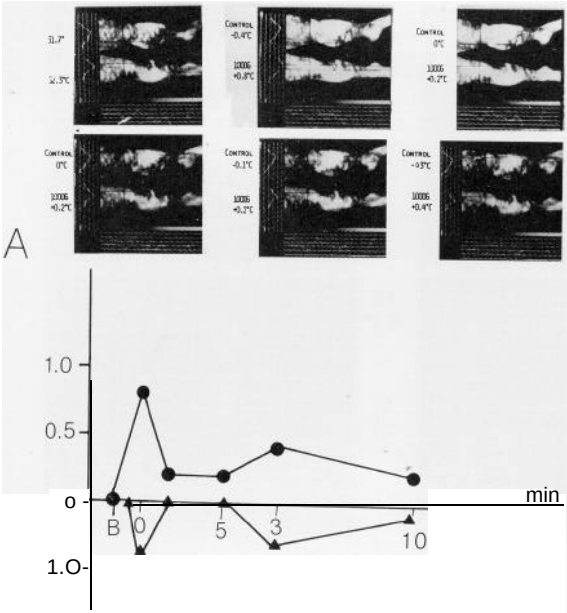


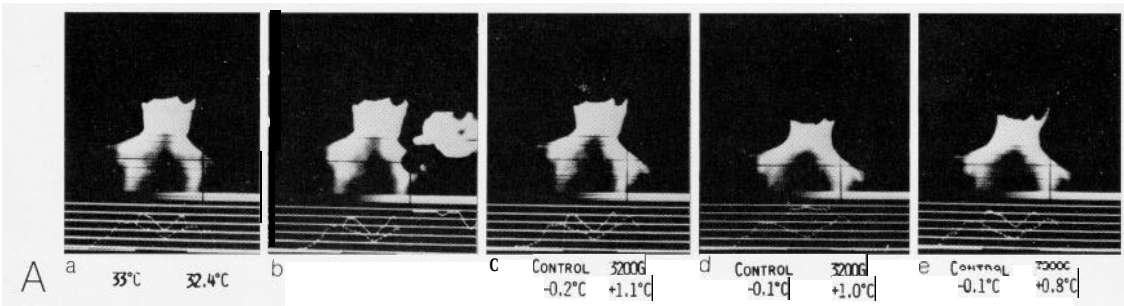
Fig. 9 A-B. A) T. of the right leg affected by gonitis. Rotating magnetic stimulation (1000 G, 5 min). Controlateral leg as reference. a: before stimulation; b: stop of stimulation; c: 1 min after stimulatiom ; d: 3 mins; e: 5 mins; f: 10mins. B) Temperature changes (of the right knee affected by gonitis.

cases of ++, 7 cases of + and 3 cases off were detected by analysis.

D) DISCUSSION

In the study of thermal effect of rotating magnetic generator, it may be considered that the heat production of instruments by themselves will influence the temperature on the contacting skin regions.

1. Therefore, the **control instruments** of vibrator and motor only were constructed in the same size and shape as the rotating magnetic generator. These 4 instruments, -400 G and 1000 G of rotating magnetic generator, vibrator and motor only - were operated simultaneously, continued their driving for 5 mins in room temperature and then stopped their operation. their T. before and after driving were taken by infra-red camera. From the analysis of the T. on the rotating magnetic generator, vibration and motor only, the specific thermal effect of magnetic



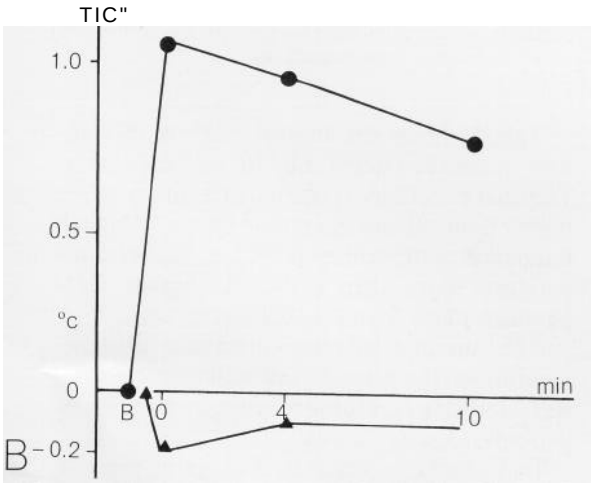


Fig. 10 A-B. A) T. of the posterior neck of a patient affected by bilateral omo-arthritis. Rotating magnetic stimulation of the right side. Left side as a reference. a: before stimulation; b: during right side stimulation; c: stop of stimulation; d: 4 mins after stimulation; e: 10 mins. B) Temperature changes of right side of the posterior neck in a patient affected by omo-arthritis.

Tab. I. **Thermal effect Of rotating magnetic generator (1000 G, 3200 G) on Clinical Cases utilizing infra-red thermography.**

I°	Sex	Age	Disease	Region of stimulation	Magnetic energy G	Region of temperature measurement	Grade	Duration	tive impro-vemeni
1	F	19	R. supra-scapular pain	R. supra-scapular	3200	R-L. supra-scapular	+++	8<	++
2	F	41	L. hemiplegia	L. lumbar	3200	R-L lumbar	++	9<	+
3	F	67	R-L. omoarthritis	L. posterior neck	3200	R-L. posterior neck	+++	I O <	+ +
4	F	48	R. gonitis	R. patella	1000	R-L. legs	+	10	+
5	F	24	Contusion of r. knee	r. patella	3200	R-L. patella	+	4<	+
6	F	58	Lumbago	I. lumbar	3200	R-L. lumbar	+	<8	2
7	M	40	Retrospondylolisthesis	L. lumbar	3200	R-L. lumbar	+	<5	+
8	F	42	Cervicodynia	L. posterior neck	1000	R-L. posterior neck	ılı		+
9	F	75	Gonitis deformans	L. lumbar	3200	R-L. lumbar	+		+
0	F	83	Knock knee	L. patella		R-L. legs	++	<5	+
1	F	81	R. gonitis deformans	R. patella	3200	R-L. lumbar	+	<5	f
2	F	37	R. upper limb neuritis	r. supra-vascular	3200	R-L. deltoid	++	IO<	+
3	M	76	R. omoarthritis	R. lumbar	3200	R-L. lumbar	+	IO<	+
4	F	37	Contusio? of neck	Posterior neck	3200	Posterior neck	f		zk
5	M	50	Lumbago	R. lumbar	3200	R-L. lumbar	+	IO<	f
6	F	50	R. thigh pain	R. thigh	3200	R-L. thigh	+ + +	I O <	+ +

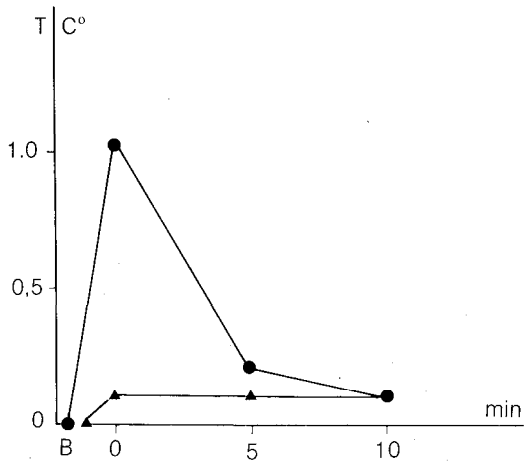


Fig. 11. Temperature changes of the right knee previously fractured. Rotating magnetic stimulation (1000 G, 5 mins = 0). Controlateral knee as reference (A).

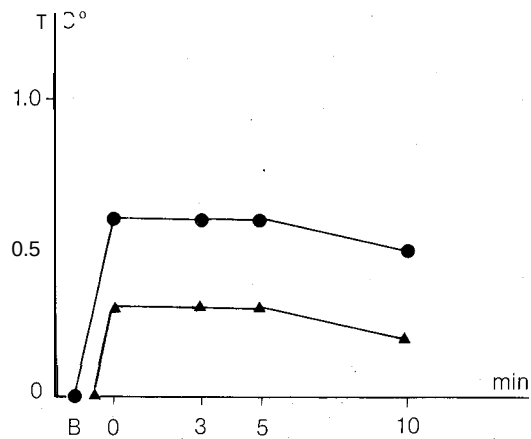


Fig. 12. Temperature changes of the right upper limb in a patient affected by neuritis. Rotating magnetic stimulation (1000 G, 5 mins = ●).Controlateral upper limb as reference

(4 .

generator itself was neglected compared with those of vibration and motor.

2. In the experiments of **healthy subjects,** 1000 G of rotating magnetic generator were applied and stimulation of vibration was used as control. In these experiments, higher temperatures were maintained in the regions of 1000 G stimulation compared with those of controls.

3. In the **application on the patients,** 3200 G of rotating magnetic generator were used for the stimulation on the pathological regions. Control of T. was taken on another symmetrical region without stimulation. In these clinical applications, thermal effects of 3200 G of rotating magnetic generator on pathological regions were detected and subjective improvements of the patients were approved.

E) CONCLUSION

The newly designed, rotating magnetic generators were constructed and the in-vivo thermal effects of the magnetic stimulations were investigated by the method of T. The thermal effects - increase of temperature on the surface of stimulating regions - of 1000 G and 3200 G of rotating magnetic generators were approved on 20 healthy candidates and 75 patients. The thermal effect is considered as the results of the promotion of blood circulation in deep tissue under the stimulating regions. Therefore, it may be considered that the rotating magnetic generator will bring good results for health.

Assessment criteria for inf ra-red thermography systems

by K.H. FRIEDRICH

Optic Research Laboratory, Carl Zeiss, Oberkochen (West Germany)

Summary. The profitable and successful use of infra-red thermographic systems depends on 2 factors. The first is the value of the information gleaned from the image generated by the thermal radiation of the area observed, but equally important is to purchase the right instrument for the purposes intended.

The design of thermal images is described and comparative performance data are given. Particular emphasis was placed on the performance limits and their practical significance.

Key words: thermography systems, technical design, performance data.

A) INTRODUCTION

To be able to assess the efficiency of thermography (T.) systems the practical requirements to be met have to be examined first. Practical temperature measurements and the presentation of temperature distributions have shown that in many cases contact thermometry is liable to unacceptable errors and that its use entails too high staff costs.

In this case and in fields where contact thermometry cannot be employed at all, non-contact thermometry can be an invaluable aid. Infra-red thermometers or infra-red T. systems, however, are much more expensive. For this reason the decision in favour of this investment requires a careful analysis of all technical and economic aspects. The following paper attempts to explain the specifications of infra-red T. instruments and to facilitate the selection of the optimum system configuration for the task in hand.

6) REQUIREMENTS TO BE MET BY INFRA-RED THERMOGRAPHY SYSTEMS

For temperature measurements in the medical field a working range from 10°C to 45” C is normally sufficient. In this range the tem-

perature display should be direct and contain small errors in absolute values. To detect very small temperature differences high thermal resolution is needed. A good measurement reproducibility is achieved only with high long-term stability and calibration equipment for periodic checks and corrections of measurement errors.

For thermal image display at least a monitor for black/white T. with normal and inverted greytone mode is needed.

As the human eye can only differentiate about 10 grey tones on a black/white monitor with random intensity distribution, colour-coded thermal images considerably help in qualitative image evaluation.

If very small hyperthermal or hypothermal areas are also to be discovered in a thermal image the T. instrument must provide high geometrical resolution and thus a high number of resolvable picture cells.

Direct quantitative statements on thermal images are difficult and unreliable. So there is some justification in the demand that a temperature oscillogram along a selectable temperature profile line be blended in. Often the display of individual isotherms is also very useful.

Various uses call for rapid information on the average temperature within defined integration limits. This type of evaluation - its information value is still being disputed - requires the implementation of the appropriate operation mode.

The scope of equipment needed for thermal image documentation is dependent on application. The low-priced and often used photodocumentation does not afford the possibility of a subsequent image evaluation based on different criteria. Besides, it has the disadvantage of a loss in information due to the photographic material.

The storage of digitized thermal images on magnetic tapes or disks permits access to the complete image information at any time. This way a most reliable basis is created for comparative studies as performed, for example, in therapy control.

Mathematical thermal image analyses for diagnosis or therapy control call for digital, computer-compatible systems. The use of data-processing equipment also provides the advantage of rationalized working processes in clinical and medical practice.

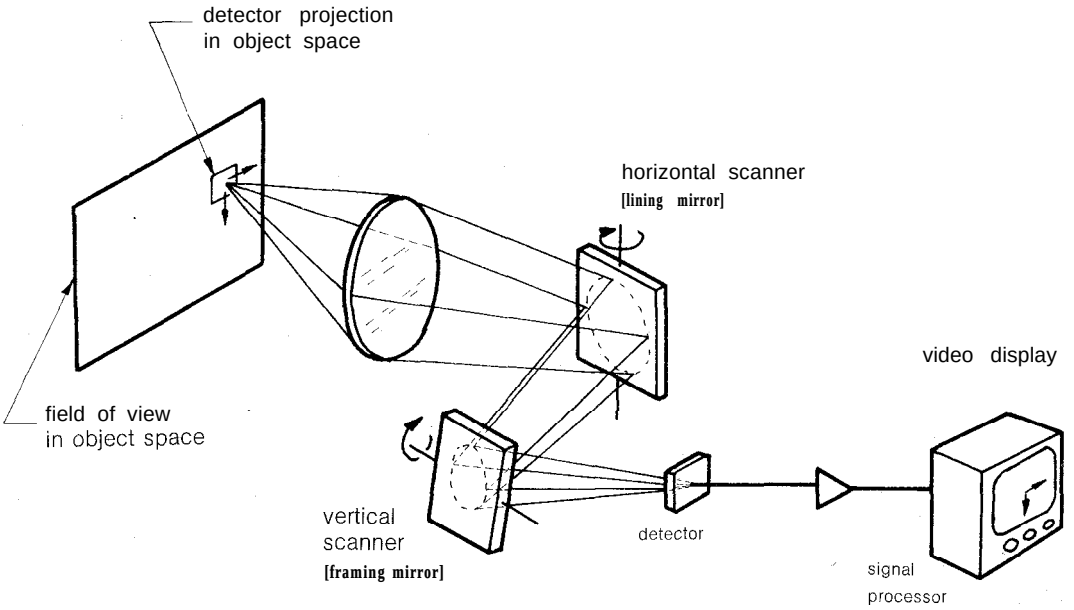


Fig. 1. Two dimensional scanning: principle of operation.

Tab. I. **Technical of infra-red thermographic modules.**

Transformation of infra-red radiation into electronic signals	Signal processing	Display functions
Optical imaging	Signal amplifing	Greytone image
Scanning	Synchronisation	Colour image
Detection	Range and level controlling	Temperature profile
	Temperature calibration	Isotherms
		Integration boxes

Tab. II. **Technical data of** detector, **scanner and optical system.**

Optics	Scanner	Detector
Focal length	Frame rate	Detector material
Focus range	Lines per frame	Spectral range
Field of view	Resolvableelementsper line	Coolant
Detector angular subtense		Coolant hold time
Homogeneity		

CI THE TECHNICAL ASSESSMENT OF THERMOGRAPHY SYSTEMS

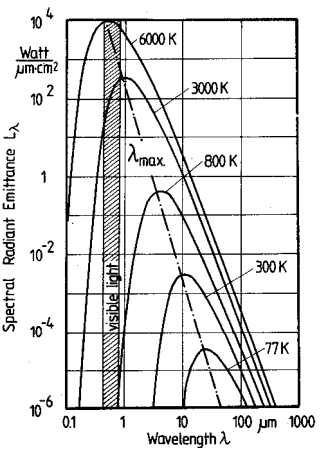
Fig. 1 shows the general design of T. systems _ with an approximately point-shaped detector which receives the radiation from the object area via the optical imaging components. This way the detector only covers a small section of the object area: the detector field of view. With a 2-dimensional scanner the detector field of view is moved across the total field of view which is determined by optical parameters.

The detector produces electrical signals proportional to the radiance reaching it. These signals are amplified and reproduced correctly located on the monitor and synchronous with the scanner motion. Special electronic equipment transforms the signals proportional to radiance into signals proportional to temperature. Tab. I shows the 3 main groups of technical functions to be implemented by a T. system. With these in mind the technical data will be discussed and assessed in the following.

1. Spectral range

Tab. II gives the system specifications for radiation measurements. According to PLANCK's law (Fig. 2 and 3) the maximum of spectral radiance is at about 10 µm and the derivative of this law has its maximum at about

Planck $L_\lambda = \frac{C_1 \lambda^{-5}}{\exp(C_2/\lambda T)-1}$ $\left[\frac{watt}{\mu m\,cm^2}\right]$ $L = \int_0^\infty L_\lambda d\lambda = \sigma \cdot T^4$ $\left[\frac{Watt}{cm^2}\right]$ Wien $\lambda_{max} = \frac{2900}{T}$ [µm]



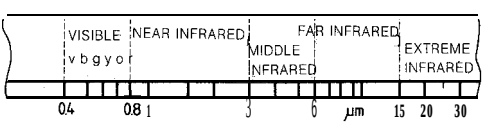


Fig. 2. The electromagnetic spectrum.

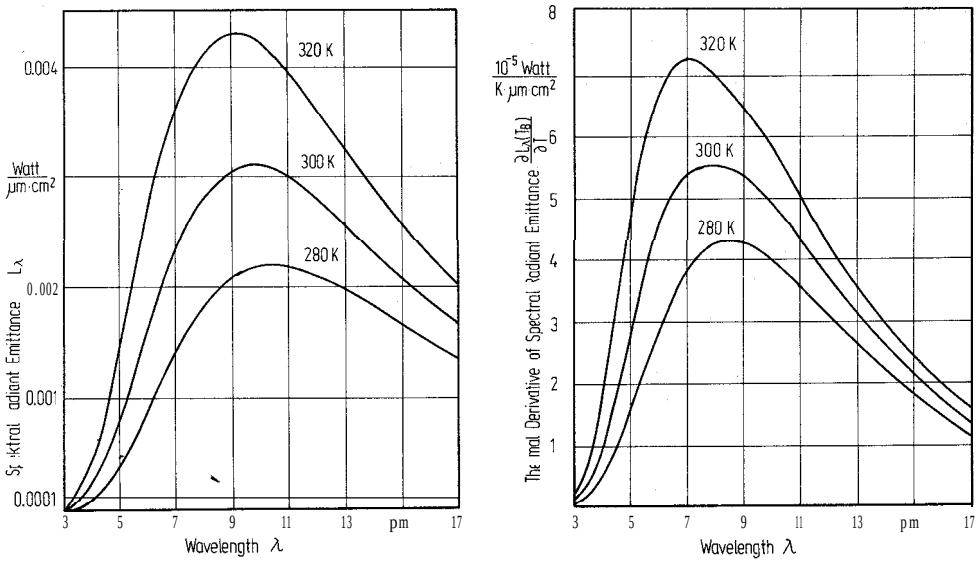


Fig. 3 PLANCK's law for spectral radiant emittance and its thermal derivative.

8 µm for black bodies having a temperature of T = 30°C.

As part of the radiation spectrum is lost on its way from the source to the detector owing to atmospheric absorption (Fig. 4) it is plain to see why specifications giveranges of 3-5 pm or 8-14 pm. For measurements over short distances, however, these ((atmospheric windows)) are not important.

Important, however, is that medical T. instruments can optimally operate only in the spectral region from 8-14µm. Therefore the detectors must be chosen accordingly, Fig. 5 shows the normalized detectivity of different ditectors as a function of wavelength and of their operating temperature. Detectors must

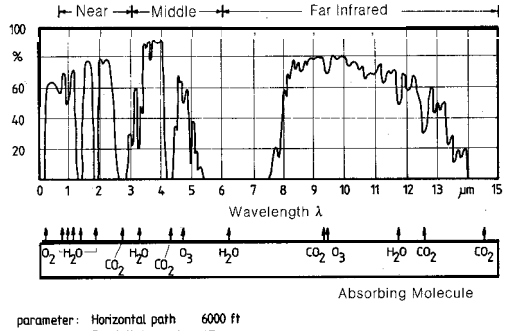


Fig. 4. Transmittance of atmosphere.

be selected so that their detectivity is as high as possible in the spectral range chosen and so that not too much cooling equipment is needed. For operating temperatures around 77 K – easily obtainable with liquid nitrogen – and the range from 8-14 µm proven detectors of the following materials are available: Hg Cd Te and Pb Sn Te. Detectors of InSb are most suited for the 3-5um region but do not have the efficiency needed in the medically important temperature range for the above reasons.

2. Geometrical resolution

The main difference between different T. instruments is due to the frame rate. Here the user must decide whether advantages of a real-time presentation of thermal images compensate for the loss in information due to the fairly low geometrical or thermal resolution as compared with slow-scan instruments. Information is lost because the signal bandwidth must become larger with constant picture cell number and increasing frame rate and this results in a deterioration of the thermal resolution x if the frame rate is to be increased without any loss in thermal resolution, however, the necessary bandwidth limitation results in fewer picture cells.

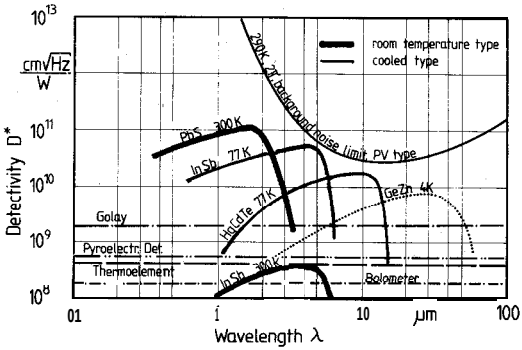


Fig. 5. Spectral response characteristics of various detectors.

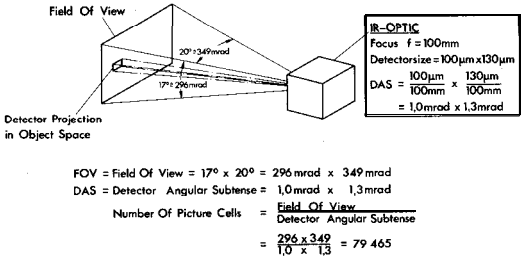


Fig. 6. Calculation of number of picture cells.

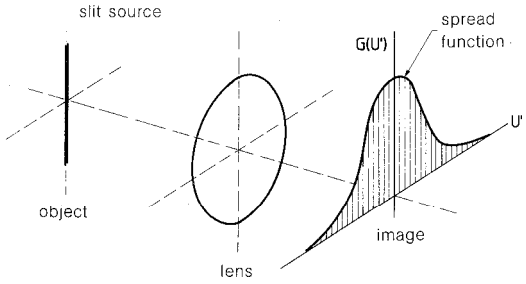


Fig. 7. Intensity distribution in the image of an incoherently illuminated slit.

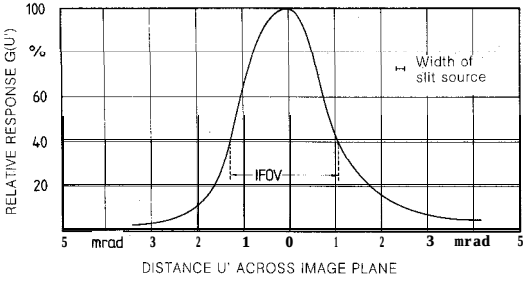


Fig. 8. Line-spread-function (LSF) and instantaneous field of view (IFOV).

A reliable assessment of the information of the usable picture signals at the output of the amplifier chain setting behind the detector is difficult because many manufacturers do not provide clear data.

The number of detector areas fitting into the object area without overlapping (Fig. 6) best illustrates the geometrical resolution. However, the picture cell number obtained this way is only an arithmetic quantity. The actual geometrical resolution depends on further factors (optics, electronics).

As the unambiguous parameter for geometrical resolution the instantaneous field of view (IFOV) can be defined as that width at which the line spread function has dropped to 40% (Figs. 7 and 8). This way compatibility with RAYLEIGH'S criterion is achieved.

With the line spread function the geometrical faithful reproduction can be completely described. This function describes the spatial distribution of a signal supplied by a very narrow slit.

From the line spread function (LSF) the modulation transfer function (MTF) can be derived. The MTF shows the modulation (monitor contrast normalized for target contrast) with which a target detail of a certain spatial frequency is transmitted.

Spatial frequency R is the number of cycles of a sinusoidal signal distribution per length or angle unit. The units are either l/mm or l/-mrad. For better illustration also lp/mm or lp/mrad (lp = line pairs) are used.

The MTF can be measured with objects having 'a sinusoidal intensity distribution, or, in thermal infra-red, with objects having a sinusoidal temperature distribution. As an approximation a square wave target can be used (Fig. 9); in this case, however, corrections are necessary. It is best to determine the MTF by the FOURIER transformation of the LSF. We can even define: the MTF is the absolute magnitude of the FOURIER transformation of the LSF.

3. Sensitivity and noise-equivalent temperature difference (NETD)

The noise-equivalent temperature difference (NETD) is the temperature difference between 2 black sources producing a signal-

to-noise ratio of 1 in the video signal. By noise we mean the effective value of the noise. As signal-to-noise ratios of 1:1 are difficult to measure, in practice a temperature difference ΔT_S is set which lies clearly above the noise amplitude. In this case the following relationship exists between signal voltage V_S, noise voltage V_R and ΔT_S (Fig. 10):

$$\frac{V_R}{V_S} = \frac{NETD}{\Delta T_S} \text{ or } NETD = \frac{V_R}{V_S} \cdot \Delta T_S$$

The NETD corresponds to the integrated noise contributions of all spatial frequencies. The NETD cannot directly be used to specify image quality, mainly for 2 reasons:

a. The NETD is determined with the video signal. The display (in combination with the eye) provides further chronological and spatial information.

b. In the NETD the noise of all spatial frequencies is added; for a certain target size mainly the noise at the relevant spatial frequency is of importance.

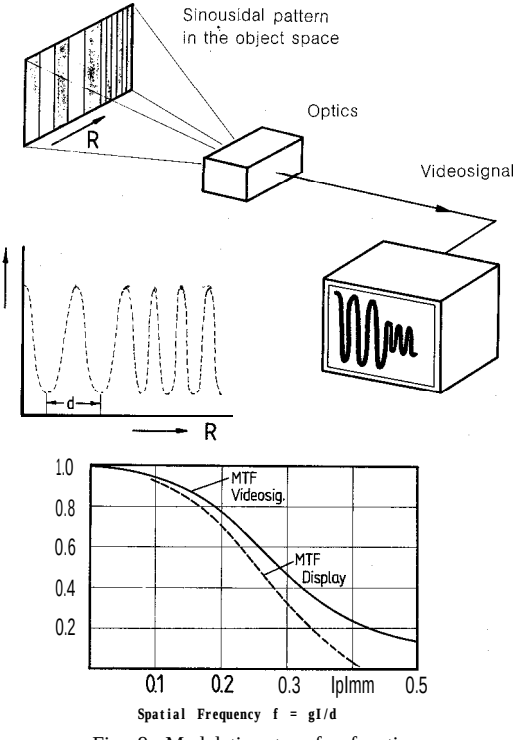


Fig. 9. Modulation transfer function.

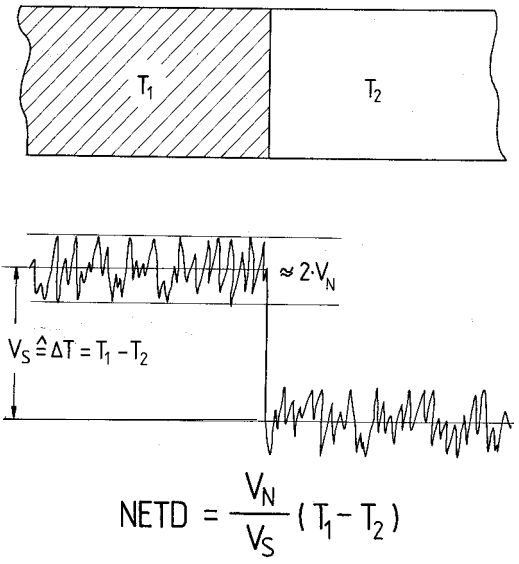


Fig. 10. Noise eqivalent temperature difference.

Therefore there are objects which can be resolved and which have a smaller temperature difference than the equivalent NETD. However, as the NETD can be easily measured it is particularly suited to determine the efficiency of a system if the video signal is used for evaluation.

A quantity describing the system performance with regard to image quality, i.e. the performance as perceived by the viewer, is the

MRTD = minimum resolvable temperature difference.

The MRTD is a function like the MTF and not a figure like the NETD. The function value of the MRTD is determined by the minimum temperature difference between a test pattern at certain spatial frequency and a uniform background at which the test pattern is still just resolved on the monitor by the viewer. By varying spatial frequency in the pattern the complete function can be obtained.

The value of the MRTD depends on both the spatial frequency and the type of test pattern used. Therefore the test pattern must be standardized. For the infra-red region a four-bar pattern with a height-to-side ratio of 7 : 1 has been introduced which should always be used. Fig. 11 shows a measured MRTD.

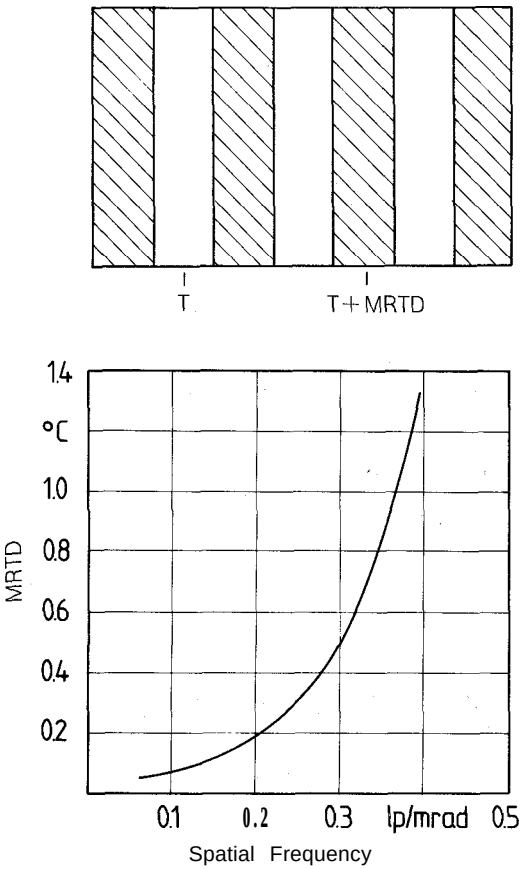


Fig. 11. Minimum resolvable temperature difference.

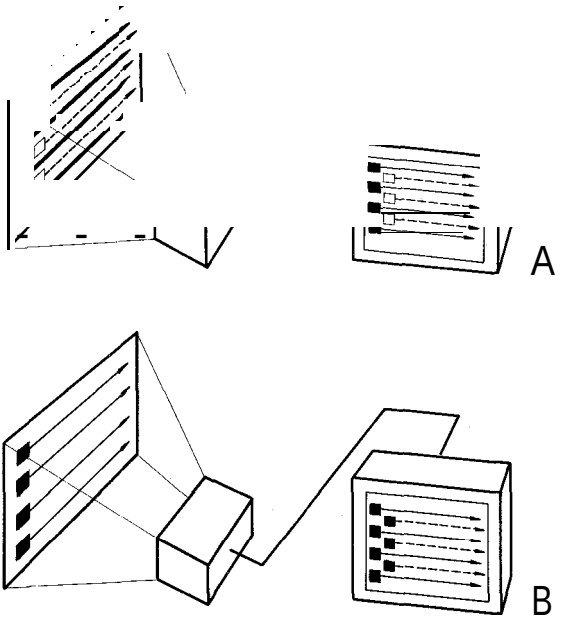


Fig. 12 A-B. Interlace procedures. A) Additional information by scanning and simultaneous display interlace. B) No additional information by more display interlace.

The MRTD is a subjectively measured function. There have been various approaches to objectify procedures by measuring the spatial power density of the noise. The measurements and their resultant parameters are at an experimental stage and still being disputed. But it is only a question of time until objective noise parameters will be used analogous to the MTF describing the geometrical imaging qualities. This will permit objective and quantitative predictions of the performance of a system as to noise and geometrical imaging quality.

D) SYSTEM SELECTION

For objects whose temperatures change rapidly or for moving objects one will always use real-time instruments and put up with the fairly low geometrical and thermal resolution. In these instruments the actual information content can be increased with a special interlaced scanning. Here intermediate lines are picked up by a tilting lining mirror (Fig. 12). This procedure is called pick-up interlace or true interlace. Of course, display electronics must work synchronous.

Often, however, only a display interlace is employed. A scanner sweeps across a raster with gaps between the lines. The monitor then shows thermal images in a chronological sequence displaced by one or more lines This way the viewer sees a line-free image but the information content is not increased.

T. instruments with long framing times (e.g. 1 s or 2 s) afford high thermal and geometrical resolution. As the visual interpretation of such slow-scan T. is fatiguing even with persisting monitors a photograph of the thermal image will usually be evaluated first.

To avoid repeated photographing, the manufacturers of these instruments offer pseudo real-time systems. These systems write the thermal image first into a storage from which it is then rapidly read out and displayed as a

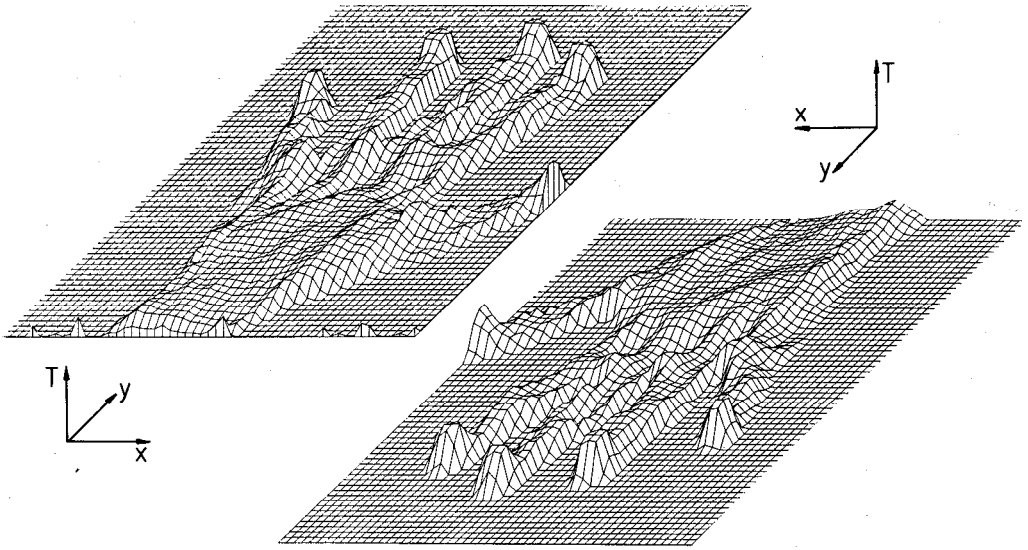


Fig. 13. Computer aided evaluation of thermal images.

standing image, e.g. according to TV standards. With such instruments it is important to know whether an analogical or digital storage is provided. Analogical storages are subject to drift, that means their memory hold time is limited. Digital storages do not have this disadvantage.

Another important aspect in assessment is the image homogeneity. With this is meant the even sensitivity over the entire area of the thermal image. Instruments using refractive optics and scanners yield results which are not as good as those of instruments with reflective imaging systems. For this reason the image homogeneity is often electronically improved in these cases. The best image homogeneity can be obtained with reflective optics and mirror scanners, with scanning being done in the parallel beam path.

For quantitative evaluation of T. the T. system should have an internal reference source and a temperature display which can be calibrated. This way a direct and absolute temperature display is obtained, e.g. with a line scan and data on the temperature range and the temperature level blended into the thermal image (Fig. 13). Quantitative evaluation with an external reference takes longer and calls for skilled and reliable personnel.

Summing up it can be said that slow.scan instruments will gain in importance although they cannot show rapid temperature changes over the entire area of a target. In view of the low human thermal conductivities it is still doubtful whether T. at intervals shorther than 5 are informative at all.

E) PROBLEMS IN APPLICATION

A great problem in T. measurements is to achieve a high reproducibility. Today T. systems with high long-term stability are available. Even the difficulties, users often experience in setting the correct temperature range and temperature level, can be reduced with electronic aids. The **Zeiss Ikotherm**, for example, is provided with an automatic mode in which the upper temperature level is electronically set so that it corresponds to the maximum target temperature. This ensures that hot spots - even with very small dimensions - are covered by the measurement range. The physician only has to set the size of the range or instruct his staff accordingly.

Digital image storages permit the use of data-processing equipment. If suitable evaluation programs are employed they can relieve the physician of the routine work and draw his attention - e.g. via diagnostic factors - to patients needing further examination.

However, the examination success also depends on reproducibile secondary conditions such as room temperature, humidity, patient preparation, etc.

Infra-red T. systems can perform non-contact measurements of surface temperature distributions without disturbing the heat convection field of the object. The conditions for a high diagnostic information value of surface temperature distributions must be set in practical application.