A thermographic index for the assessment of ischemia

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Summary. A quantitative procedure for the thermographic examination of hands and feet is described. A mild thermal challenge resulting in a digital hyperemia in normal subjects, is compared with a group with vasospastic disease. A thermal gradient is shown in the legs and feet, which is altered in lower limb ischemia. The potential of these simple techniques is in the follow-up treatment.

Key words: thermography, quantitation, Raynaud's, ischemia.

A) INTRODUCTION

Thermal imaging of the extremities provides a simple non invasive portrayal of the temperature distribution along a limb. Since ischemic conditions produce a fall in temperature from the normal, thermographic (T.) representation can be quite dramatic. Gross changes in temperature are usually clinically obvious and are often associated with changes in skin colour. However, small progressive changes observed in regular follow-up patients, or difficult border line cases, call for a more sensitive approach.

B) THERMOGRAPHIC INDEX FOR THE ASSESSMENT OF ISCHEMIA

A standardisation procedure, established for serial T., was used and is shown in Tab. I. The thermograph (Bofors Mk3) mounted on a parallel stand, was kept at a distance of lm from the subject. This distance provided a field of view adequate for the examination of a hand or foot. Larger areas were scanned from a distance of 1.3m. The T. was processed after digital conversion and displayed on a colour TV monitor in 0.5% isotherms from red (hot) to dark blue (cold). Constant areas of interest were selected from the T. and Thermographic Index (T.I.) calculated from the isotherm distribution.

$$T.I. = \frac{\Sigma(\Delta t \cdot a)}{A} \qquad \begin{array}{l} t = 24^\circ C \\ a = \text{area of isotherm (cms)} \\ A = \text{total area measured (cms)} \end{array}$$

Tab. **I. Standardisation for serial thermograms.**

1. Ambient temperature: 20°C ± 0.5°C	
Humidity	: 60% f 8%
2. Patient acclimitisation:lO mins	
3. Thermograph scanning distance: (a) 1 m	
(b) 1.3m	
Temperature range: 24°C - 34°C	
(Reference 34°C)	
4. Region of interest selected for measurement, expressed as T.I.	

Over a temperature range of 24-34°C this T.I. scale for hands and feet was recorded from 0.1 to 10.0. Temperatures below 24°C were recorded as a minus value.‘, [3]

1. The hand. After stabilisation most normal subjects presented hands of an even temperature. Square areas measured (cms) over the dorsal hand and dorsal fingers (held together) were between 3.5-5.5 on the T.I. scale.

To develop a manageable routine for stress testing of patients with vasospatic disease we did not employ the ice cold challenge used by other workers. Details of the themal stress procedure are shown in Tab. II. It was evident that a mild cooling stress to the hand achieved by 60 s immersion in water at 20°C could produce digital hyperemia or recovery within 10 mins in normal subjects (Tab. III).

Tab. **II. Thermal** Stress.

1. T. of dorsal hand (with reference temp.)
2. Immersion in water at 20°C 60 s. (plastic glove)
3. T. of dorsal hand 4 mins
4, T. of dorsal hand 10 mins

2 h before the test. Concomitant drug therapy should also be noted.

Once these items are recorded, it is possible to make reliable examinations of reactive hyperemia to cold. Individual values for the T.I. from both the dorsum and the digits of the hands vary both before and after stress testing. However, differences (A T.I.) can be shown to progessively change in individual patients on therapy, and mean values show significant changes if a large enough sample of patients are studied.

Tab. III. **Thermographic Index of hands.**
(T = 24°C)

	PRE CHALLENGE			POST CHALLENGE		
SUBJECTS	Dorsal (a)	Digital (b)	ΔT.I. (b-a)	Dorsal (c)	Digital (d)	ΔT.I. (d-c)
Asymptomatic Controls						
Mean	6.09	5.11	−0.79	4.88	4.99	+0.11
SD	(2.0)	(2.1)	(1.5)	(2.5)	(2.8)	(1.2)
n = 25						
Raynaud's Phenomenon (+RA)						
Mean	6.20	4.1 7	-2.03	5.59	3.38	-2.21
SD	(2.0)	(2.2)	(1.9)	(1.8)	(1.8)	(1.4)
n = 40						
Scleroderma						
Mean	4.38	0.67	-3.7	2.81	-1.6	-4.3
SD	(0.8)	(1.7)	(1.6)	(1.1)	(1.1)	(1.3)
n= 12						

Patients with mild vasospastic conditions failed to produce a digital hyperemia, although dorsal hyperemia might be seen within the test time period. Patients with vasospastic disease failed to show a hyperemia response and remained with low T.I. values for 30 mins or more (Tab. IV).

If this procedure is carried out at 20°C (convenient for other T. examinations) the patient should wear the same amount of clothing and the legs and feet should be kept warm. Emotional stress should be avoided, and several baseline values should be taken. Those who smoke must be asked to refrain for

2. The lower limb. Stress testing of the lower extremities has proved more difficult to achieve. However, by the use of colour coded T., for a standardised temperature range a reproduceable thermal gradient can be shown, particularly from the lateral view of the leg.

Patients are scanned, seated on a chair (Fig. 1) with the knee in flexion and the foot placed flat on a stool some 10 cms below seat height. By placing a metal mirror over the anterior foot, a mirror image of the toes can be seen in

Tab. Iv. **Mean thermographic index - Lower limb.**

SUBJECTS	1 Lat. Tib. Tub.	2 Ankle	3 toes 1 3	AT Index I - 2	 I - 2	 2 - 3
Normal (S.D.) n= 10	6.40 (0.8)	4.69 (0.8)	3.73 (0.8)	2.67 (1 .0)	1.71 (0.8)	0.96 (0.4)
Ischemic (S.D.) n= 10	4.52 (1 .0)	2.27 (2.4)	0.51 (1.9)	4.01 (1.9)	2.25 (1.8)	1.76 (0.6)
			Student t =p	p=<0.2	p=<O.OI /	p=<oo5

the same field of view. From measurements of temperature expressed as T.I., it is observed that 3 areas were prominent for a simplified expression of the gradient (Fig. 1). a) a square area 5 *X 5* cm over the *lateral tibial tuberosity;* p) a square area 5 x 5 cm immediately proximal to the *malleolus;* y) a square area 5 x 5 cm over the *anterior toes.*

In the normal leg the difference in T.I. between the proximal and distal sites may be 2 °C or less. However in patients with ischemic

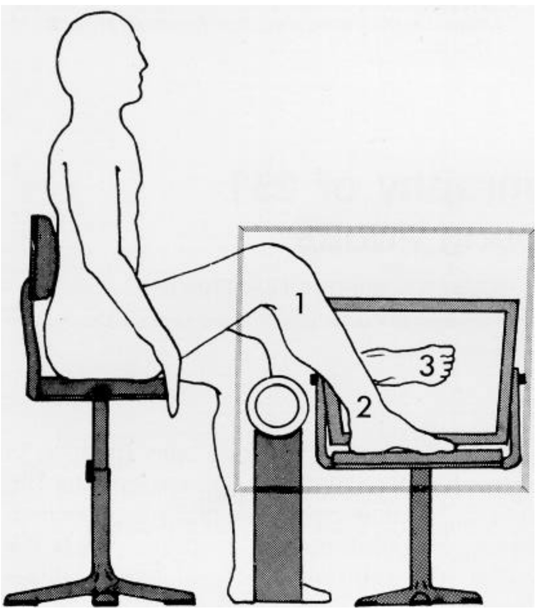

Fig. 1. Scheme for quantitating T. of the lower limb. (1 = - lateral tibia1 tuberosity; 2 = malleolus; 3 = anterior toes).

lower limbs the gradient between the lateral tibial tuberosity and the ankle may be greatly increased (Tab. V).

Post treatment values with an oral vasodilator drug have shown a similar pattern to that observed in the hands. However the greatest change has occured in the distal site and A T.I. between the 3 sites have been greatly reduced. The results of this study will be reported later. However, it can be shown that by careful standardisation, T. is a powerful non invasive tool for quantitating this form of drug therapy.

Similar results have been observed in a study of lumbar sympathectomy where T. is one of the very few techniques suitable for repeated objective evaluation. The use of a numerical T.I. greatly facilitates the analysis of the data. This fact is particularly important in

Tab. **v. Termographic index of lower limb.**

Subjects	casts	Lat. tib. tub.	Ankle	Toes
Normal	1	7.09	6.28	5.37
	2	5.32	4.01	4.20
	3	6.64	5.30	4.82
Lower	4	3.93	2.12	1.51
limb	5	4.38	2.61	1.95
ischemia	6	5.42	1.10	0.81

pharmacological studies and removes the subjective and often inadequate comparison of T.

C) DISCUSSION

1. The hand. Any investigation which is dependent on the peripheral vascular reaction has many pitfalls. Some of the factors listed are known to influence hand temperature, and careful precautions should be observed. It is also imperative that careful control of the scanning equipment is made before any quantitation can be utilised.

Investigations into the use of this procedure for the objective quantitation of vaso-active drugs are promising. Studies with a high dose vasodilator drug have provided interesting information, showing the transient rise in temperature frequently observed with these drugs, are this case followed by a slow sustained increase in response to thermal stress after 3 months of treatment. This increase has been shown to be independent of climatic and seasonal changes, providing the subject is stabilised in the constant environment. The technique, which is not arduous for the patient, provides an objective non invasive means of studying the effects of oral or parenteral drugs.

2. The lower limb. Despite the fact that thermal stress to the feet has proved more difficult than the hand, useful information has been obtained from the temperature gradient of the leg. LOVISATTI et al.[2] showed that the longitudinal thermal gradient is approximately 3°C on the anterior lower limb. Author's technique uses the lateral aspect with a mirror image of the toes. The temperature gradients have also been used to monitor geriatric patients with lower limb ischemiaon oral vasodilator therapy. The technique has also proved useful for the evaluation of lumbar sympathectomy, as one of the few investigations suitable for repeated objective investigation.

The use of a T.I. (or mean temperature difference) simplifies the data, and removes the subjective and inadequate comparison of thermal pictures. Similar results can be obtained by using the mean temperature measured with an integrator, if calibrated over the same temperature range.[4]

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Scrotal thermography of 231 «normal» young adults

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Summary. A protocol for thermography (T.) of the scrotum is described with attention to positioning of the patients and dynamic evaluation using the Valsalva manoeuvre (V.M.). The mean normal scrotal temperature is 29.35°C±0.18°C. The threshold value of 32°C appears to be significant for the diagnosis of varicocele. Results point out the increased sensivity of the technique when combined with V.M. in diagnosis of small or even subclinical varicocele. Scrotal T. with V.M. is indicated in all evaluations of sterility.

Key words: scrotal thermography, Valsalva manoeuvre, varicocele, normal scrotum, sterility.

A) INTRODUCTION

Varicocele is a benign disease which, in general, causes so little discomfort to the patient that it may go unrecognized. However, its impact on qualitative and/or quantitative aspects of the spermogram with resultant harmful effects on fertility has long been established.

Scrotal T. has become a routine investigation in this condition. A review of the literature fails to show a standardized protocol for the procedure; in addition there are too few studies of normal healthy patients.' The Authors had the opportunity of studying a sample population of young adult males drawn from a military contingent. These subjects were presumed normal. However, a number of varicoceles were discovered and studied.

The VALSALVA manoeuvre (V.M.) was utilized in conjunction with T.; this manoeuvre has been shown to increase the sensitivity of T. in the diagnosis of small varicoceles.

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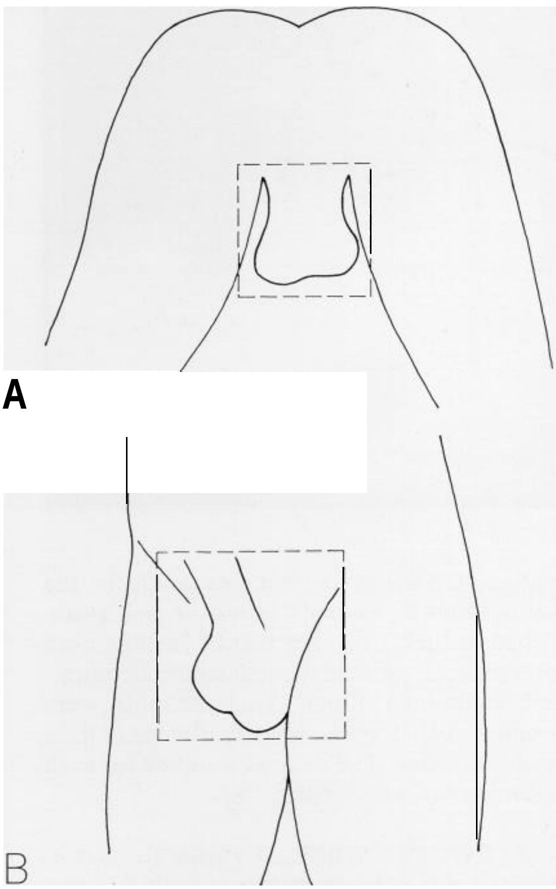
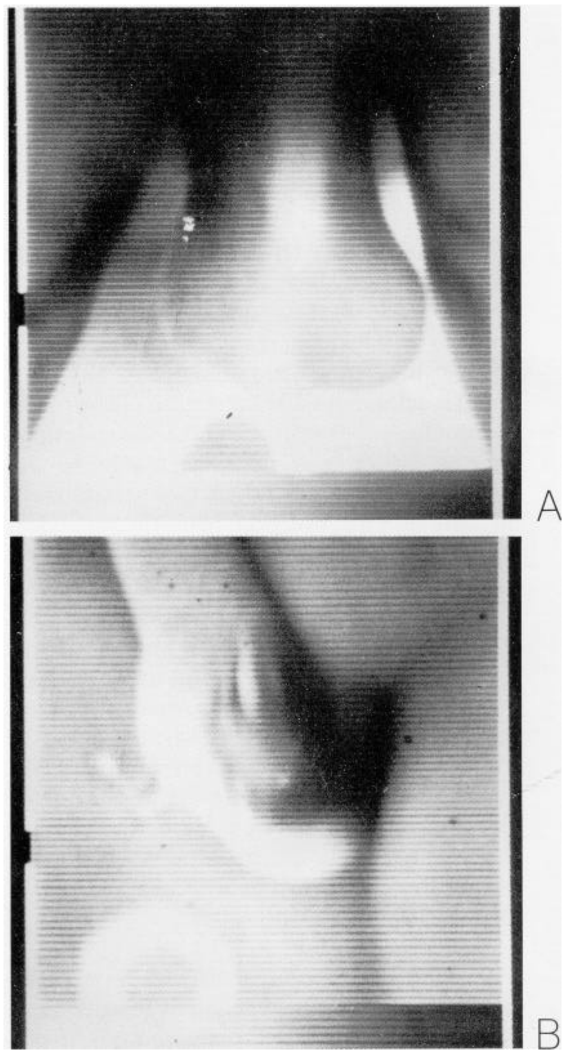
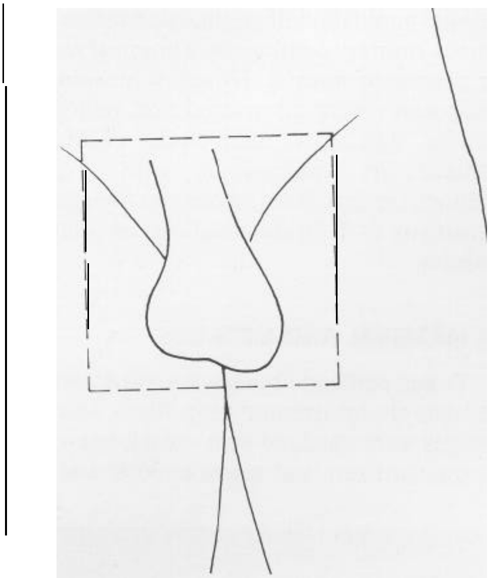


Fig. 1 A-B. Left varicocele. A) Knee-elbow position posterior view. B) Left anterior oblique view with the patient standing, unmasks hyperthermia related to varicocele.

B) MATERIAL AND METHODS

T. was performed using an AGA 680 infrared tele-thermographic unit. Black and white images were obtained with ((black-hot)) mode. A standardized heat sauce at 30°C was inclu-





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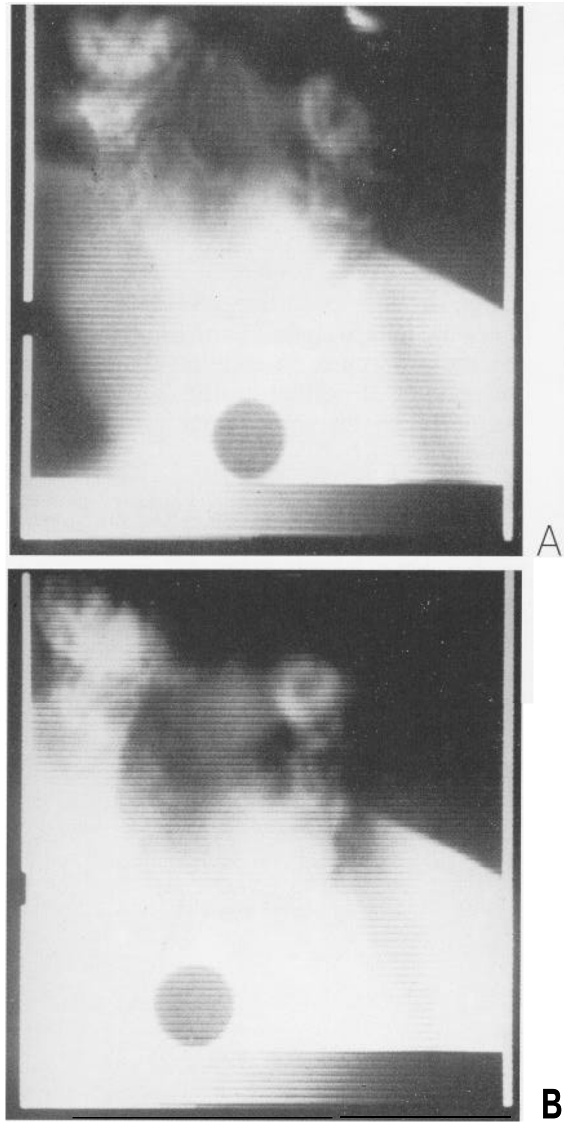

Fig. 2 A-B. Normal scrotum. A) Left anterior oblique view. B) No significant modification after V.M.

ded in the camera field to allow direct measurement of absolute temperatures.

1. Positioning the patient for examination. Some authors state that the best position for the examination is the knee-elbow position with legs spread, using a posterior-anterior incidence.* Physiologically this position does not permit visualization of the renal-spermatic venous reflux. Fig. 1 shows a left varicocele which was not discernable in the knee-elbow position. When this patient assumed the standing position, hyperthermia became evident on the left anterior oblique view. Examination was thus carried out with patients in the standing position; the penis was lifted and held in place against the abdomen with adhesive tape. A cardboard square was placed behind the scrotum to provide insulation against neighbouring hyperthermias. Due to cost consideration photographs were usually only made of the frontal views but every scrotum was systematically examined in the right and left anterior oblique positions which have proven to be the most appropriate and useful for the purposes of this study.

2. Practical considerations. Hair in the genital region may be a sauce of thermal artefacts since it acts as a screen to infra-red radiation. Shaving the patients would be the ideal solution. Patients turn-over was established in such a manner that 10 patients were present at all times in the temperature-controlled examining room. Thus patients were examined after approximately 10 mins of thermal adaptation. The average duration for each examination was 3 mins.

3. Dynamic study. All patients performed a V.M. This adjunct to examination was considered to be of fundamental importance. Since no clinical examination of varicocele

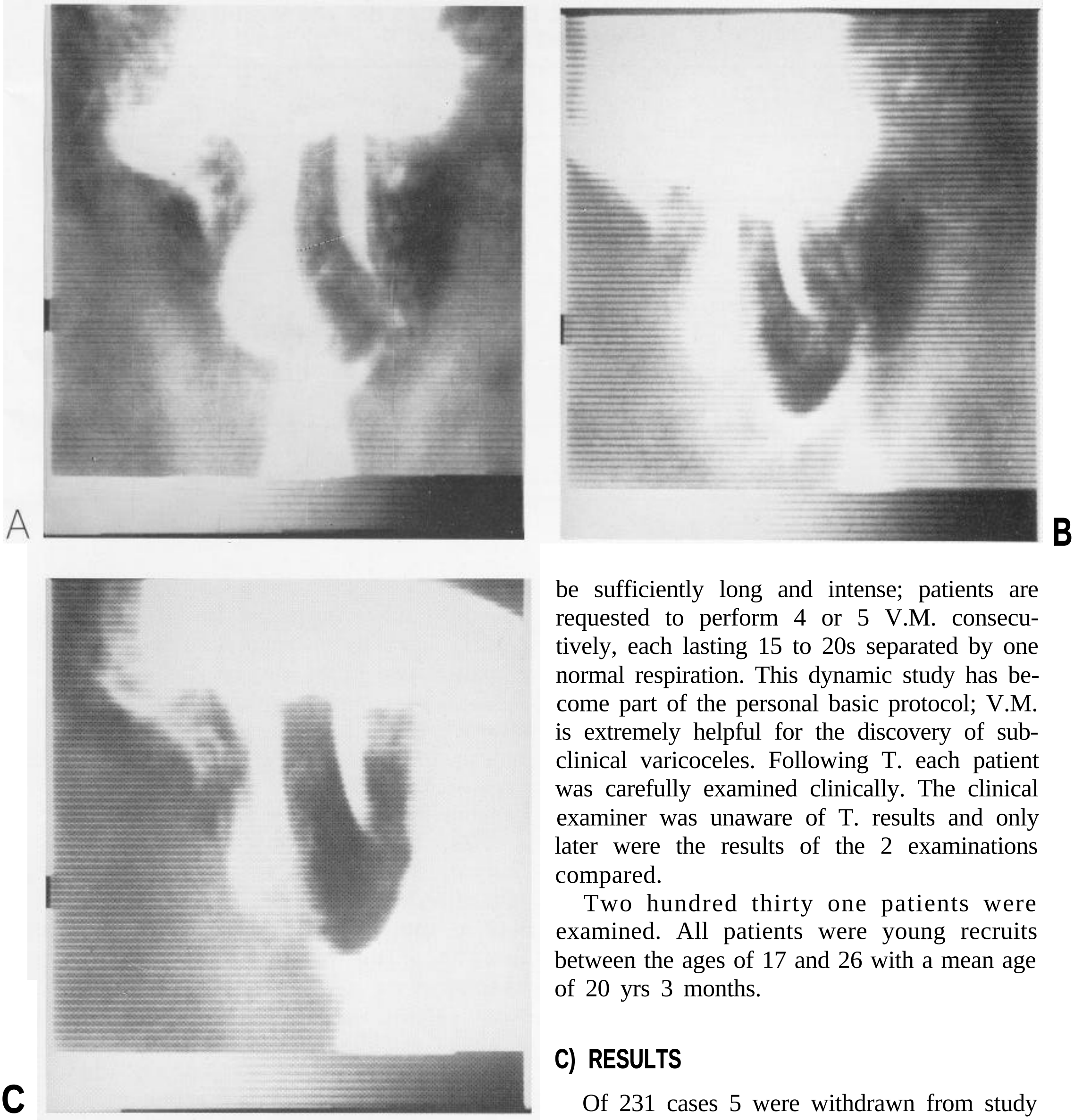

Fig. 3 A-B-C. Left varicocele. Influence of V. M. A) Left anterior oblique view. B-C) Successive T. show increasing temperature under V.M.

would be complete without requesting the patient to perform the V.M., T. cannot be considered adequate without V.M. The increased peripheral venous pressure consecutive to the V.M. causes no T. modification in the normal subject (Fig. 2). In varicocele V.M. increases the sensitivity of thermal imaging by markedly increasing the surface and/or the gradient of scrotal hyperthermia (Fig. 3). The V.M. must be sufficiently long and intense; patients are requested to perform 4 or 5 V.M. consecutively, each lasting 15 to 20s separated by one normal respiration. This dynamic study has become part of the personal basic protocol; V.M. is extremely helpful for the discovery of subclinical varicoceles. Following T. each patient was carefully examined clinically. The clinical examiner was unaware of T. results and only later were the results of the 2 examinations compared.

Two hundred thirty one patients were examined. All patients were young recruits between the ages of 17 and 26 with a mean age of 20 yrs 3 months.

C) RESULTS

Of 231 cases 5 were withdrawn from study due to artefacts or other technical difficulties. The results of clinical and T. evaluation are shown in Tab. I.

1. Clinical examination. On palpation there were 177 normal scrotums, 22 varicoceles (approximately 10% of all cases), 7 boys with thickened cords and 20 boys with miscellaneous benign non inflammatory abnormalities including 16 epididymal cysts, 3 hydroceles and 1 testicular agenesis.

2. T. examination. A normal T. is defined

Tab. I. **Clinical and thermographic correlations for 226 young adults presumed «normal».**

Thermography \ Clinical pattern	Normal	«Thick coras"	Varicoceles	Miscellaneous scrotal abnormalities	Total
Normal thermogram	171	4	–	19	194
Thermal asymmetry and/or hyperthermia <32°C	6	1	1	1	9
Hyperthermia >32°C	-	2	21	-	23
Total	177	7	22	20	226

by overall isothermia and no thermal asymmetry. Scrotal temperature is lower than that of the penis. Analysis of normal T. yielded a mean normal scrotal temperature of 29.35°C ± 0.18°C. Only the 171 boys who were both clinically and T. « normal » were used for this calculation.

D) DISCUSSION

Of the 177 subjects judged clinically normal, 6 had an abnormal T. which was not modified by V.M. These cases may represent false positives; however no further explorations were undertaken in these cases and their true status remains in doubt.

In this small series the incidence of varicocele (20/226: 10%) is slightly lower than in previous studies of military personnel.

All 22 cases of varicocele were associated with abnormal T. No false negative results were seen. These T. abnormalities principally consist of an area of marked hyperthermia over the varicocele or more generalized hyperthermia over one of the scrotum as previously described.

Quantitative evaluation of hyperthermia disclosed a threshold of 32°C; 95% of varicoceles (21/22) had temperatures greater than or equal to 32°C. Conversely subjects with scrotal temperature superior or equal to 32°C were found to have varicocele in 91% of cases (21/23). The absolute increase in temperature is also related to the clinical grade (Tab. II). While it is generally agreed that an unilateral varicocele has repercussion on fertility by increasing the temperature of the contra-lateral testicle, in this series no contra-lateral rise in temperature could be demonstrated.

V.M. should permit to approach the mechanism of varicocele, its extent in function of the maximal surface area of hyperthermia as well as the regurgitant venous flow rate in function of the rapidity of progression or desappearance of hyperthermia.[3] This dynamic study should aid in distinguishing various types of varicoceles: due to excessive afferent blood flow, to obstruction of venous drainage or to simple venous reflux.

If only the 177 normal cases and the 22 variceles are considered, T. yields 100% true positives, 3% false positives and no false negatives. T. would thus appear to be a reliable objective tecnique complementary to clinical examination. It also provides a useful means of appreciating the results of surgery.

E) CONCLUSION

The purpose of the current study was to evaluate a series of normal subjects. The

Tab. II. **Analysis of thermographic** reSultS **according to the Clinical grade of varicocele.**

Thermography \ Clinical grade	+	++	+++
Normal thermogram	–	–	–
Thermal asymmetry and/or hyperthermia <32°C	1	–	–
Hyperthermia >32°C	4	8	9
Mean maximal temperature (°C)	33,2	33,5	33,9

Authors were able to determine certain normal values and confirmed the usefulness of the V.M. Furthermore the incidence of varicocele in this population was determined; it has shown that large scale screening for this potential cause of sterility is technically feasible. T. represents an ideal complement to clinical evaluation of varicocele in that it is at once simple, reliable, accurate, inexpensive and non invasive, thus meeting W.H.O. criteria for screening techniques. For the practitioner these same qualities are indications of the usefulness of T. in the evaluation of all cases of sterility where dynamic study is especially indicated, since it is known that pathologically confirmed subclinical varicoceles giving normal patterns on standard T. may become obvious after V.M. Of course there still remains the unresolved question of the responsability of varicocele as a cause of masculine sterility, but this is another problem.

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Report of thermographic breast biopsy correlation

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Summary. Contact thermography (CT.) in correlation with breast biopsy shows 82% increased thermal response. Mammography (M.) had a 64% correlation. T. had half the false positive rate of M. Thermal biology of the breast is significant in cancer of breast.

Key words: contact thermography, breast biopsy, pathology, correlation, thermal-biology.

A) INTRODUCTION

The bio-thermal analysis of the breast is significant. In-vitro growth of normal cells and malignant cells produces the same heat energy; on the other hand, malignant tumours in-vivo produce or store more heat than normal tissue.[3] Angio-genesis occurs in malignant growth and the conduction and convection of tumour thermal energy to the blood flow is of extreme importance. The thermal engineering of tumours has been studied thoroughly and heat transfer from the tumour can be measured by blood flow.' All the answers are not in but is thought that the thermal biology of the tumourt is directly correlated with blood flow. Blood flow can be directly measured by thermography (T.) and recent experiments suggest it may be the most accurate method.[6] In addition to the thermal bio-engineering confirmation of T., recent verified studies correlate doubling time of tumours to thermal energy output. With shorter doubling time such as 40-50 days much more heat is generated whereas 400-500 doubling time tumours approach the thermal energy of normal tissue.[4]

B) MATERIAL AND METHODS

A cooperative study of pre-operative T. was instituted in May, 1978 at 4 Institutions. It was agreed that every scheduled breast biopsy (B.) would be controlled with T. The T. would be analyzed objectively and then the T., M. and B. correlation would be made.

The cholesteric analysis profile (CAP[tm]) method was chosen for the recording of the thermal biology of breast disease in this study. This was done because of the more complete and accurate qualities of contact thermography (C.T.). In addition the thermal pattern recognition (USA method) and the more significant absolute temperature difference (delta T) (European method) were combined as criteria. This added twice the information usually obtained from Tele-T. The exams were read in 5 classes: TH 1 (normal-nonvascular), TH 2 (normal-vascular, TH 3 (equivocal-l factor), TH 4 (abnormal-2 factors), TH 5 (abnormal-3 or more factors). The data presented in this paper are the cooperative efforts of B.J. King, Luther Hospital, Eau Claire, Wisconsin, J. Weiss, Grandview Hospital, Dayton, Ohio; R. Klein, Kettering Hospital, Dayton, Ohio, W.B. Hobbins, Wisconsin Breast Cancer Detection Foundation, Madison, Wisconsin. The study will run through December, 1979 and material presented is for the first twelve months. 129 breast specimens have been analyzed to date with pre-operative T. Within the 129 specimens there were submitted: 3 from breast augmentations, 3 from breast reductions and 1 male breast biopsp The T. classificatil in these cases was TH 1 or TH 2 except for I breast augmentation case which was TH 4. These cases are included in the statistics wherever appropriate. They are excluded from the benign comparative results.

Cl RESULTS

1. In 129 specimens, 34 **cancers** were recovered from the biopsies (26%). This figu would be actually higher if the 6 plastic cases were excluded. In the cancer cases, 4/34 were uncovered as a results of T. alone providing the final stimulus for biopsy (11%). T. was abnormal in 28/34 cancer cases (82%). These figures are according to the world literature (84% detection rate in some 1954 cases).' l/34 cancers with 2.5 cm diameter and no axillary nodes was thermally cold (TH 1); 5/34 cancers were thought as vascular normal (TH 2). 21/28 cancers with T. abnormal, there was 1. pattern of TH 4-TH 5 (62%); in 7/28 (25%) cancers with T. abnormal, there was T. pattern of TH 3.

By comparison, 25134 cancer cases were mammographed: only 13/25 (52%) were called carcinomas; 3/25 (12%) cancer cases were called suspicious and 9/25 (36%) cancer cases were called normal. The overall accuracy of 64% for M. (52%+12%) also correlates to previous experience. T. was the most accurate modality for correlation with bioptic results, in this series.

2. Correlation of T. in the **benign lesion** was also accurate. There were 84 such cases and 7184 (8.3%) were class TH 4 and TH 5. The TH 3 cases were 20/84 (24%). Normal T. were found in 57/84 benign lesions (68%). 68/84 benign cases were mammographed and a report encouraging biopsy occured in 29/68

Tab. I. **Thermo-bioptic correlation in malignant and benign lesions** (129 breast specimens).

Biopsy	Thermographic class					Total
	THI	TH2	TH3	TH4	TH5	
Cancer	1	5	7	14	7	34/129
	(18%)		(20%)	(62%)		(26%)
Benign lesions	14	43	20	7	0	84/129
	(68%)		(32%)			(65%)

Biopsy	Mammographic class			Total
	abnormal	equivocal	normal	
Cancer	13 (52%)	3 (12%)	9 (36%)	25 (19%)
Benign lesions	29 (43%)	17 (25%)	22 (32%)	6% (53%)

(42%). There were 17/68 (25%) benign cases in which the findings were equivocal. Normal or benign M. was correctly found in 22/68 benign lesion (32%).

T. had also a false positive rate of 32% as compared with M. false positive rate of 68% (43%+25%). This is significant and will hold to the end of the series.

Tab. I and II show the breakdown of cases for both cancer and benign cases for T. and M.

In lo/34 (29%) cancer cases there are negative axillary nodes: 80% of these patients had abnormal T. In 24/34 (71%) cancer cases there were axillary nodes involvement: 100% of these patients had T. abnormalities. The one cancer patient with a TH 1 T. in this series had no nodal involvement.

D) CONCLUSION

At the present time it appears that T. is a high risk marker in breast cancer screening. In this series there was abnormal T. in 84% of the breast cancer cases proven by biopsy. This compars with the results of Wisconsin Breast Cancer Detection Foundation screening: in 8000 women there was found 2.1% cancers, 86% of which had abnormal T.[5] T. remains the highest risk marker we have to date. T. is not only the highest risk marker but the most significant biological marker for malignant grade of the tumour. Already most European Tumour Centers are planning their therapeutic programs around the thermo-biology of the tumour.

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