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Medical thermography

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Australian Institute of Health

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Foreword

This report was prepared following preliminary consideration of medical thermography by the National Health Technology Advisory Panel in 1989. The study was developed further by the Health Technology Division within the Australian Institute of Health. It involved an extensive review of the literature and includes comments from a number of persons and organisations with an interest in the use of thermography and related issues.

Contents

Summary

- Medical thermography is a technique for the measurement and display of the distribution of body surface temperature. The principal method used in determining skin temperature is infra-red (IR) sensing.
- The report reviews the literature on the technology and its applications in various areas including neuromuscular, rheumatological and vascular problems.
- Although it is widely used, the role of thermography has yet to be established and there are conflicting opinions in the literature on its efficacy.
- There appears to be an absence of rigorous trials to establish the efficacy of thermography, and a lack of data on its effect on patient management and on its cost effectiveness.
- The potential range of applications is wide and the costs of thermography to the health care system could be substantial. Evidence of corresponding benefits appears to be lacking.
- More research is required to establish if it has a clinical role in the Australian health care system.

Medical thermography

Introduction

Medical thermography is a technique for the measurement and display of the distribution of body surface temperature. The technology is being used as a diagnostic aid in a number of clinical conditions including some neurological, rheumatological and vascular disorders. The principal method used in determining skin temperature is infra-red (IR) sensing. The technique has been used in Australia since about 1986.

During its use in the clinical environment over the past 20 years, thermography has been a controversial diagnostic tool. Thermography does not yet appear to have achieved general acceptance by the medical profession. Poor results obtained in the diagnosis of breast cancer in the 1970's and the view that temperature distribution carries little specific information have contributed to the reluctance of doctors to use the technique.

Nevertheless there are indications that the use of thermography in Australia, particularly in the evaluation of musculoskeletal problems, is increasing. Thermography units are predominantly located in diagnostic and pain management centres where they are used, in the main, in the diagnosis and management of pain. However the clinical usefulness of thermography is being questioned in Australia, particularly by third party insurers. In view of the uncertainties in the diagnostic value of thermography and signs of its increasing use, it was decided to examine this technology.

This report draws on the substantial literature review by the US National Centre for Health Services Research and Health Care Technology Assessment (NCHSR)(1), reviews the more recent literature, and includes comments on the technology received from users, individuals and professional medical and scientific bodies in Australia and overseas. Some conclusions are drawn on the value of thermography in clinical practice.

Physiological basis for thermography

Temperature change associated with disease has been known for centuries. The development of instrumentation to produce thermal maps of large surfaces has provided a new approach to the study of body heat in health and disease.

The skin is a highly efficient radiator with peak emission of radiation occurring in the infra-red range of the electromagnetic spectrum. Detectors have been developed to respond in this range of radiation. The amount of radiation emitted is a function of a number of factors such as blood circulation and type of surface.

Radiation from the surface of the skin is markedly affected by small increments of body motion and by dermatologic abnormalities of the skin surface. Also, different areas of the skin react differently and at different speeds to temperature changes. The hands and feet respond rapidly because of a large blood volume in relation to the small skin surface. The arms and legs are slower to respond because of a less favourable relationship between the heat content and the skin surfaces. The head and neck have a large skin area and slower response, with smaller variations in the skin temperature(2).

Temperature differences in one area of the body may affect the temperatures in other areas by vasoconstriction or vasodilation; the forehead is particularly sensitive and influential. The main factor determining skin temperature is blood flow, the amount of which is controlled by vasoconstriction of the smaller vessels. Active impulses of the sympathetic nerves cause the walls of the blood vessels to constrict; as they subside the walls dilate passively. Clearly, skin temperatures vary widely, both at the same site and from site to site under basal conditions.

The amount of blood and its rate of flow through skin capillaries is thought to account for the greatest portion of the thermal image obtained by thermography (3). Since vasoconstriction and dilation of skin vessels is largely controlled by the sympathetic nervous system it is thought that thermography may provide a way of monitoring that system's physiological function. If the model is correct, pathophysiology of anything that may cause abnormal sympathetic nerve function is potentially visible through thermography. Thermography may also provide empirical evidence of primary circulatory abnormalities, skin lesions and inflammation, although there is some controversy about the physiological genesis of abnormal thermographic findings(3).

The American Medical Association's Council on Scientific Affairs, in its evaluation of thermography, has noted that a growing body of basic research supports clinical and experimental observations of interactions between sympathetic nerve fibres and afferent pathways(4). Various general and autonomic mechanisms have been proposed as the pathophysiologic basis for skin temperature changes in neuromuscular disorders. Among the proposed general mechanisms are localised muscular action, antidromic stimulation of sensory nerves and activation of sinuvertebral nerves. Proposed mechanisms implicating the autonomic system include stimulation of the spinal parasympathetic nerves or the sympathetic vasodilatory system, thermal alterations resulting from sympathetic vasoconstriction, and segmental regulation by the somatosympathetic reflex. The Council considered that although each of the proposed mechanisms have merit, it is probable that the ultimate pathophysiologic basis for thermographic changes in neuromuscular disorders will include portions of all these theories. LaBorde has pointed out that the absence of an unequivocal scientific basis does not preclude the existence of an observed clinical thermal phenomenon(5).

The American Medical Association Council reported that abnormal thermograms occur in conjunction with vasomotor dysfunction which cannot be demonstrated by conventional radiological studies of the spine or peripheral structures as thermography demonstrates physiology and not anatomy. The presence of significant temperature difference between corresponding areas of opposite sides of the body is suggestive of nerve impairment, since defective vasomotor mechanisms result in thermal asymmetry. As thermal asymmetry is the hallmark of abnormality in thermography, the patient serves as his own control.

In the acute stage of a peripheral nerve injury, a temperature increase results in the area of nerve distribution. As the nerve regenerates the affected area becomes colder. In nerve root irritation there is an ipsilateral temperature decrease in the corresponding dermatome(4). (A dermatome is an area of skin corresponding to a spinal cord segment. Dermatomes may overlap so that two segments supply a single skin area. Knowledge of the dermatomes is used in the localisation of spinal cord disorders(6).

Edeiken and Shaber have challenged the basic concepts of thermography in a brief review of the physical, physiologic aspects and theories of thermography and its clinical use in musculoskeletal conditions(2). They stated that pain is influenced by local, systemic and environmental variables. They argued that patients with pain may have skin temperature changes, but many patients have pain without them, and many have comparable changes without pain. They also argued that there is no convincing scientific data that show that nerve irritation causes a specific anatomic distribution of skin temperature changes of specific dermatomes. Such non-dermatomal distribution has been shown by Ash et al(7) and by So, Aminoff and Olney(8).

Types of thermographic equipment

The recording of skin temperature is achieved by two principal techniques, contact and non-contact measurements.

In contact thermography a thermal sensor is placed in contact with the body surface. Contact temperature measurements with thermocouples and thermistor probes are well known. There are difficulties with these single point measurement methods in reproducing the point of measurement and in measuring thermal distribution. The contact thermographic technique mostly used in a clinical environment is liquid crystal thermography.

Non-contact thermography measures surface temperature by detecting electromagnetic energy emitted from the surface, either at IR or microwave wavelengths. Methods include radiometric and scanning techniques. Developments in radiation detection methods have led to more widespread use of IR scanning devices for medical use.

Liquid Crystal Thermography

Liquid crystal thermography (LCT) uses elastomeric sheaths which are impregnated with liquid crystals (cholesterol derivatives). By specific mixing, preparation of liquid crystals may be formed for medical use with response temperatures between 18° and 40°C. The sheaths are commercially available, either mounted on frames or as flexible sheets with different ranges of temperature response for each formulation (typically 4-5°C).

Up to seven colours may be visible on the detector ranging from brown through tan, yellow, green, blue-green and blue. The detector is chosen so that 75 per cent of the resultant colours are in the orange to yellow range. The resolution of the technique is 0.5 to 1°C relative to the adjacent colour.

When the liquid crystal sheet is brought into contact with the area of interest, the flexibility of the sheath allows it to conform to the anatomy. Upon contact with the body, the crystals absorb heat and change structurally; the sheath then changes colour in a pattern corresponding to the temperature pattern of the skin. Once the maximal colour change for the detector has occurred this pattern is photographed immediately after the sheath is lifted slightly from the skin surface (to eliminate distortion and glare). Abnormal thermographic images are repeated at least three times to confirm their reliability.

The LCT has some limitations in that the detector must be pressed against the skin surface to be examined. This may cause distortion of the anatomical image and the region being examined may rise in temperature because the transmission of heat by radiation is blocked. Also absolute temperature measurement and quantitation are not possible except by rough estimation of colour ranges and distribution.

Infra-red Thermography

The development of newer infra-red detectors in recent years has contributed to the increasing interest in this form of imaging.

A typical IR thermography system consists of a scanning unit, an output amplifier, a computer processor and a picture display monitor. The scanning unit contains a system of optics for focusing the radiant thermal energy on the detector (usually cadmium mercury telluride). The detector is mounted in a small Dewar flask and cooled with liquid nitrogen to optimise its sensitivity. Some machines use liquid argon-cooled detectors. A shutter placed in front of the detector causes the input from the object to alternate with input from a control reference heat source installed in the device, making it possible to continuously compare and measure the temperature of the object against the constant control temperature. The detector converts the incoming IR rays into electrical signals which are processed and displayed on an imaging screen.

Newer thermography units incorporate thermo-electrically cooled detectors which eliminate the need for cooling agents such as liquid nitrogen. The Australasian College of Physical Scientists and Engineers in Medicine (personal communication) has advised that one of the disadvantages of these newer types of detectors is that they are slow in cooling the detector to the operational temperature. This would affect the thermogram and any absolute temperature measurements made if inadequate time has not been allowed for.

Images are generally shown as contour maps, with each isothermal area being displayed in the same shade of grey or in the same colour. The assignment of colour to a specific temperature is arbitrary, and colours are used only to aid interpretation. IR thermographic systems are capable of discriminating differences as small as 0.03°C(9). In addition the computer processor enables measurement of spot temperatures, average temperatures in a given area and performance of digital subtraction of one area from another(10).

Ash and coworkers discussed the potential sources of errors involved when imaging curved surfaces of the living body (such as the back) using IR thermography(11). The curved surface used in their experiment was a balloon filled with approximately 2 litres of water at 26° Celsius which was placed on a stand and viewed at a distance of one metre. Temperature measurements of the balloon surface were reproducible within a 0.2°C range. The balloon was rotated 90°, 180°, and 270°, and photographed in each position. Four distinct colors were seen in each view, representing a 4°C range. By adjusting the scale in either direction and maintaining 1°C colour separations, a central warm area remained at the site closest to the camera, consistently measuring 5-10 cm in diameter and representing a 1°C higher temperature. They commented that an accurate method of imaging would register only one colour.

The balloon temperature recordings were compared to actual thermograms of the back, which showed trigger points. Trigger points are invariably associated with warmer temperatures centrally and cooler areas at the periphery of the convex surface. Positive thermograms show a one-colour temperature increase in the area where the tangential axis is perpendicular to the optical axis to the camera. The appearance of the central area of the balloon was indistinguishable from thermographic changes associated with trigger points.

Ash et al reviewed 300 separate thermographic views of the limbs. The same relationship was found in these thermograms. The authors also noted that similar errors are likely when the face is examined. They concluded that the margin for error associated with thermographic imaging of trigger points, thermotomes or dermotomes on curved surfaces of the body appears prohibitive. The error of measurement (1°C-3°C) is much greater than the temperature changes that are described as diagnostic of the pain of nerve fibre irritation or trigger points. With a potential error of three degrees, these positive findings fall well within the error range of the recording techniques.

The authors also discussed possible technical limitations of the technology. They noted that earlier IR detectors such as InSb detectors responded only to approximately 5 per cent of the total emitted radiation from a black body at 27°C. Modern thermographic units are equipped with HgCdTe detectors to avoid this source of error. They listed a number of possible sources of error in their paper and considered that these units are still experimental tools.

Microwave thermography

Because IR thermography (2–25μm) is only able to measure surface temperature, use of microwave frequencies (1–10GHz) is now being investigated. Microwave energy is radiated from greater depths than the surface infra-red thus making thermal imaging of subcutaneous tissues possible. However, the energy emitted from the human body is very low at microwave frequencies, being 10^{-10} less than that in the infra-red.

There are specific difficulties raised by thermography at microwave frequencies. Spatial resolution is worse than that obtainable with the present IR scanning systems. Also, measurement depth varies with frequency. In fatty tissues, it is reduced from 10cm at 1GHz to 1cm at 10GHz. Measuring depth is also dependent on water content, being lower in fat and bone than in high water content tissue such as muscle(10).

Clinical investigations are based on contact microwave radiometry, using small matched external antennae in contact with the skin. Remote sensing thermography is also possible using focused reflectors combined with scanning and processing systems to provide thermal image display.

In 1983 the US NCHSR reported on a review of National Cancer Institute-sponsored projects which were designed to determine the potential of microwave and millimeter wavelength thermography to detect breast cancer(12). The report concluded that no definitive statements could be made from the data regarding the efficacy of this technology in breast cancer detection, technical problems remained unresolved and that widespread clinical acceptance based on adequate clinical trials were unlikely in the near future.

Williams and Ring have commented that preliminary work has shown that brain tumours and spine and hip lesions demonstrated by IR thermography may produce definite changes on the microwave thermogram(10). Swain and Grant have cited the work of Manson et al who used microwave thermography to assess peripheral vascular disease and found that it was more clinically useful than IR thermography(13). Barrett et al have reported the use of microwave thermography in breast cancer detection(14).

Microwave thermography is still experimental and few articles have appeared in the medical literature describing its use in clinical practice.

Commercially available thermographic equipment

Currently there are 15 commercial thermography systems marketed world wide (Ring, personal communication). Table 1 gives details of some models of of these.

Table 1: Examples of available thermography equipment

Type	*Manufacturer*	*Model*	Capital cost
Liquid Crystal	Novamedix (UK)	Novatherm	$A10,700
Infra-red	Novamedix (UK)	Inframetric 600M	$A75,000
Infra-red	Bales Scientific (USA)	MCT-7000	$A84,800
Infra-red	Agema (Sweden)	Thermovision 800 series	$A110,000 includes computer

Footnote: All prices are for May 1989, except for Agema whose price was for February 1990.
Source: Overseas and Australian distributors.

At present there are relatively few practices using thermography in Australia. There are between 10 and 20 IR units being used by specialists with a number of orthopedic surgeons using liquid crystal thermography. Overseas there are 450 centres in Japan and approximately 700 in the USA and centres in several European countries (Australian Society of Thermology, personal communication).

Examination protocols

In the last three years an International College of Thermology has been formed and professional organisations exist in some European countries, North America and Japan. In general, standards in Australia for thermography have been determined overseas, particularly in the US where professional bodies have been established. The two bodies in the US are the Academy of Neuro-Muscular Thermography and the American Academy of Thermology. In 1990 the Australian Society of Thermology was formed.

Standards have been developed for thermographic examinations to ensure that artefacts are not introduced and uniform protocols are followed. A standard clinical protocol for thermographic examinations has been adopted by the US Academy of Neuro-Muscular Thermography(15). However, there are concerns in Australia that appropriate protocols are not being followed in some instances (Cassar, personal communication).

Prior to examination of a patient the following instructions have been given:

- Avoid oils, skin medication, bath powder, heat or ice packs on the day of the examination.
- No smoking for at least four hours prior to the consultation.
- No X-rays, EMG's nerve blocks, acupuncture, laser therapy, physiotherapy or massage for at least 24 hours pre-test.
- No use of transcutaneous electrical nerve stimulation for 24 hours prior to the test.
- Braces, collars or other immobilisation devices should not be worn for at least four hours prior to the examination.
- No sunbathing for one week prior to the test.
- A shower should be taken on the morning of the test.

The newly formed Australian Society of Thermology has modified these instructions to include the following advice:

- Do not to eat or drink for three hours prior to the test.
- Do not to take any tablets on the day of the test.
- Avoid any exercise (physiotherapy, hydrotherapy, running cycling, housework) for three hours prior to the test.
- Do not apply friction to any part of the body.

Reference to avoidance of oils, bath powder, heat or ice packs, X-rays, EMGs, nerve blocks and laser therapy were removed (Thomas, personal communication).

The patient is examined in a draft free air-conditioned room maintained at a steady temperature between 19° and 25°C, with most rooms operating at the middle of this range (Thomas, personal communication). However, some practitioners may use temperatures in the range 24°-28°C to accentuate the effects of sympathetic dysfunction (Cassar, personal communication).

Humidity should not be at the level that produces cutaneous perspiration since this alters skin temperature through evaporative loss.

The patient removes all clothing from the area to be examined and is allowed to equilibrate to the controlled temperature for at least 15 minutes. A standard test consists of three series of images taken at 15 minute intervals. The recommended sequence of images to be taken during each of the three series depends on the part of the body being examined. At the 19th Annual Meeting of the American Academy of Thermology held in New York, May 1990, it was agreed that only one series of thermograms is required after an appropriate period of equilibration (Cullum, personal communication).

Dynamic thermography is also being used to assess activities that in the clinical setting exacerbate a patient's complaints, for example, repetitive shoulder arm movements in cases of shoulder pain (Thomas, personal communication). The symptomatic and asymptomatic sides are equally stressed by performing repetitive movements and a repeat series of thermograms obtained. It is suggested that dynamic thermography may emphasise minimal asymmetry in the non-stressed initial series and may provide important diagnostic information. Also thermal challenge tests performed by immersing the hands or feet in hot or cold water are used to dynamically stress the sympathetic nervous system and in cases of borderline baseline pathology may emphasise abnormal physiology detectable by thermography (Thomas, personal communication).

The examination, including processing of images, can take up to one and a half hours depending on the areas involved. The average time for an examination is approximately one hour (RACR and Kotzmann, personal communications).

The Academy of Neuro-Muscular Thermography has issued guidelines and indications for neuromuscular thermography. The Academy recommends that a physician, prior to interpreting a neuro-muscular thermogram, should receive specific special training in interpretation of thermograms by having successfully completed a training program approved by the Academy.

Kotzmann (personal communication) has advised that in his experience thermography has been useful in the following conditions.

- suspected cases of reflex sympathetic dystrophy
- pain which is failing to respond to treatment
- suspected lumbar or cervical disc disease where computerised tomography (CT), myelography, or magnetic resonance imaging (MRI) are inappropriate or give equivocal results
- suspected nerve or nerve root damage where electromyography (EMG) and nerve conduction studies are inadequate.

The RACR (personal communication) has stated that the views expressed by Kotzmann concerning the applications of thermography encompasses the views of the College.

A typical patient presenting for thermographic assessment has had conventional neurodiagnostic investigations, eg CT, EMG and myelography and whose problem remains undiagnosed (Cassar, personal communication).

The thermal image is always considered with a total patient presentation including history, clinical examination and other investigations. The thermogram on its own is usually meaningless (RACR and Kotzmann, personal communications).

Interpretation of thermograms

The key premise of diagnosis with thermography is that the body's surface temperature is symmetrical when comparing one side of the body to the other in normal healthy subjects (under draft-free temperature controlled conditions). Symmetry of body surface temperature represents a normal physiological function(16).

Standards of interpretation of thermograms involve viewing the entire distribution of the suspected involved nerve from the spinal column to the distal extremity in order to ascertain the condition of thermal symmetry between corresponding regions of the two sides of the patient(3). A difference of at least 1°C covering at least 25 per cent of the area of the dermatome under consideration is considered an abnormal or positive finding suggesting underlying pathology. If the abnormality correlates with other clinically positive findings such as provided by the patient's history, neurological and laboratory tests, then the information may be corroborating evidence of the complaint(3).

More recently Thomas (personal communication) has advised that the accepted definition of abnormality is a difference greater than two standard deviations above the mean in a normal population. Different regional areas of the body have different mean temperatures and standard deviations. In the analysis of thermographic studies normal values are used for that particular thermographic area. Normal values for left and right asymmetry have been determined by Uematsu(17) and Goodman(18). Further, quantitative thermographic indices have been developed in the assessment of inflammatory joint pain and in assessing intra-articular and oral anti-inflammatory drugs.

It is considered that as thermal asymmetry is the diagnostic marker for abnormality, the patient serves as his own control (Thomas, personal communication).

In interpreting thermograms the current standards apply (Thomas,personal communication):

- Visual comparison of regional areas that are subjectively painful with the contralateral normal side.
- Measurement of thermal gradients - forehead to finger tip (upper limb) and forehead to toe (lower limb) - in cases that are equally painful bilaterally where the right and left thermal asymmetry may be non-existent.
- Calculation of thermographic indices over specific joints to quantify joint inflammation and comparison with normal data to determine abnormality and severity of inflammation.

LeRoy and Filasky have stated that abnormal thermal patterns in disorders that affect the neurologic, myofascial, circulatory, and skeletal systems can be distinguished by specific pattern recognition(19). These abnormalities have been classified either as segmental neuropathic patterns or as nonsegmental patterns such as those seen in myofascial, circulatory, or skeletal disorders. In their paper the authors provided a summary of the characteristics of abnormal thermal patterns in pain syndromes.

In 1975 Silberstein et al attempted to define the normal variation in selected symmetrical areas of the human body using an IR scanner[20]. They reported that thermal differences between symmetric areas of the chest, abdomen and back never exceeded 1°C. They also found that although intra-individual variations (values of 1.5°C in a given area from day-to-day) in absolute skin temperature did occur, they occurred bilaterally and so did not affect the amount of difference between the two sides.

Feldman and Nickoloff confirmed thermal symmetry in a group of 100 asymptomatic factory workers using liquid crystal thermography[21]. The standardised examination consisted of nine images, including three of the posterior neck and shoulders, four of the forearms, and two of the hands and wrists. They concluded that the likelihood of a normal individual having side to side difference greater than 0.62°C has a probability of less than 0.005. They further commented that a 1°C thermal asymmetry should be regarded as definitely abnormal.

In 1985 Uematsu using IR thermography measured the skin temperature in 32 healthy subjects[22]. He divided the surface into 32 sensory "box" segments that approximated the areas of innervation of the major peripheral nerves. His results provided additional evidence that there are very small skin temperature differences between corresponding sites on different sides of the body.

There has been some concern by thermologists that interpretation of the thermographic image has been troubled by subjectivity. To address this concern Uematsu et al recently published a paper which described a computer-calculated method of determining temperature differences (ΔTs) between homologous sections of the body as measures of the degree of thermal asymmetry [9]. The ΔTs reported were obtained from 40 matched regions of the body surface of 90 asymptomatic normal individuals. The matched regions approximated to the areas of ennervation of the major peripheral nerves and spinal segments. The degree of thermal asymmetry was found to be very small. The value of ΔT for the forehead (mean + standard deviation) was 0.18° + 0.18°C, for the leg 0.27° + 0.2°C and for the foot 0.38 + 0.31°C. These values were reproducible in both short and long-term follow-up measurements over a period of five years. The authors concluded that the ΔT values obtained can be used as a reference standard in assessment of sympathetic nerve function in most clinical examinations, and the degree of asymmetry is a quantifiable indication of dysfunction.

However, there have been questions in the literature as to what constitutes an abnormal thermogram and conflicting results in normal subjects have been published . Although a variation of over 1°C is considered abnormal, Edeiken and Shaber have reported that, in their experience, 35 per cent of normal individuals have variations over 1°C [2]. However, they provided no details of their research.

Bogduk (personal communication) has commented that there is a need for normative data to enable the determination of changes in temperatures that exceed the biological variations, both from patient to patient and within the same patient from one day to the next, or even one hour to the next.

Ash et al in 1986 reviewed the basic neuroanatomic and physiologic aspects of the sympathetic outflow to the limbs and correlated them with the somatic sensory dermatomes[7]. They used a thermocouple thermometer to test 30 normal patients and 87 patients with clinically proven nerve root lesions. They concluded that there are no predictable sympathetic dermatomes and that their imaging by thermography is not plausible. They also concluded that since each colour of the thermogram is primarily a one-degree range, and since temperature variation in the extremities is frequently 0.5°C or more, asymmetry of 1°C isotherms should be expected more often than not.

Hubbard et al have criticised this study stating that thermocouples have been demonstrated to be unreliable compared with IR thermography for this kind of work and are not specifically recommended in the standards for neuromuscular thermography of the Academy of Neuro-Muscular Thermography(23).

The Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology (AAN) published an assessment of thermography in neurologic practice(24). In part, the assessment stated that the variabilities related to testing technique and to the influence of site, age, sex, height, weight, physiologic condition, and disease variables have not been explored adequately. Although there are published statements that age does not affect emission, the data provided are insufficient to establish that the question has been adequately addressed. The statement also noted that IR energy emission changes after nerve injury and vessel occlusion, but the underlying pathophysiologic mechanisms, particularly in chronic lesions and especially those affecting nerve roots, are not clearly understood. The influence of labile vasomotor responses and dermatologic condition needs further investigation.

Applications of thermography

Neuromuscular – lumbar and cervical pain

Many studies have focused on neuromusculoskeletal thermography and its relationship to pain syndromes, and comparisons have been made with diagnostic procedures common to the usual clinical work-ups for pain such as electromyography (EMG), myelography and CT .

Pochaczevsky et al performed LCT on 101 patients who had clinical complaints relating to the back and extremities(25). Of these, 61 had myelography. Myelographic and thermographic results correlated in 51 out of 61 patients (84 per cent) who had positive clinical findings.

Of these 61 clinically positive patients, 48 (79 per cent) had a positive LCT while only 38 (62 per cent) had positive myelograms. Thirty eight patients who had thermographic and myelographic procedures also had surgery. If only results completely proven at surgery are considered, the overall accuracy of LCT was 95 per cent and that of myelography 84 per cent. The authors stated that although this was a preliminary study with a small number of patients, the accuracy of thermography appeared to be equal to or better than the accuracy of myelography.

In 1984, Newman et al reported on the relative value of LCT as compared with physical examination, myelography, EMG and CT in the examination of 155 consecutive chronic low back pain patients(26). The results revealed 75 per cent agreement (either both tests positive or both tests negative) between neurological findings and thermography. Likewise, thermography and EMG were in agreement in 75 per cent of the cases studied. The correlation of myelography and CT with thermography was substantially lower, 54 per cent and 58 per cent respectively. Overall, thermography appeared to correlate better with physical findings and positive EMG than it did with myelography or CT. An interesting finding was that if the thermogram was negative, the probability of obtaining a positive result on the neurological examination was 5 per cent and 8 per cent in the case of the EMG study. The authors concluded that LCT appears to show some promise in the diagnostic evaluation of chronic back pain patients for whom further surgical treatment is contemplated. Much more data were needed, however, to determine its value in the diagnosis of both acute and chronic pain syndromes.

Hubbard and Hoyt have reported on their experience in a large neurology group practice with IR thermography in the evaluation of 495 patients presenting with pain(27). The thermographic findings were also compared with EMG, myelography and CT scanning results of the corresponding areas. A control group of 23 asymptomatic medical students was also evaluated with complete cervical and lumbar studies. In the abnormal lumbar studies, a positive symptom/thermogram correlation was present in 93 per cent; the correlation was 96 per cent in the cervical studies. Correlation between EMG and thermogram was 57 per cent in the lumbar area and lower extremities and 71 per cent in the cervical area and upper extremities. Myelographic and thermographic correlations were 93 per cent in the lumbar and 84 per cent in the cervical regions and CT scan correlations were 76 per cent in the lumbar and 85 per cent in the cervical regions. The data demonstrated a high correlation when thermographic results were compared with the distribution of subjective pain complaints and with other diagnostic tests. The authors concluded that the findings correspond closely to the published literature and further indicate the clinical value of thermography in pain evaluation as an indicator of peripheral nerve pathophysiology.

In a continuation of this ongoing study, Hubbard and Hoyt reported on 805 consecutive patients(28). The results compared closely with the previous series of 495 patients. They concluded that thermography is a useful adjunct to clinical examination and other diagnostic testing.

At about that time LeRoy et al reviewed the major advances in the use of diagnostic thermography in low back pain syndromes(29). They concluded that thermography had taken its place beside such tests as X-rays, EMG and CT in the diagnosis and management of patients with low back pain syndrome and the technique was past the clinical investigation stage.

Mills et al investigated the role of LCT in the evaluation of nerve root compression due to lumbosacral lateral spine stenosis in 107 patients. Twenty eight patients acted as controls(30). The results of LCT were compared with those from other investigations, with the following results: clinical assessment (107 patients), 53 per cent agreement; myelography (60 patients), 45 per cent agreement; computerized tomography (35 patients), 46 per cent agreement; electromyography (27 patients), 41 per cent agreement; and surgical findings (19 patients), 53 per cent agreement. Each method of investigation was compared against the surgeon's final overall assessment. Clinical assessment agreed in 76 per cent, myelography in 71 per cent, computerized tomography in 71 per cent, and electromyography in 70 per cent. However, agreement could be demonstrated in only 48 per cent of cases using LCT. The authors concluded that it would appear that LCT is by far the least reliable of these techniques in the diagnosis of nerve root compression.

The authors also stated that the previous report by Pochaczevsky(25) on the superiority of LCT was flawed by the way the data obtained were analysed and therefore little assessment of the specificity and usefulness of the technique could be made.

In 1986 Hubbard, Maultsby and Wexler published an analysis and review of previous prospective, retrospective and blinded studies on lumbar and cervical thermography for nerve fibre impingement(23). LaBorde recently reported on a similar analysis(5). Sensitivity, correlative data, specificity and reliability data were also considered. They found that thermography has a high sensitivity for identifying underlying lesions that might be demonstrated by radiologic procedures. Therefore, they considered that, unless strong clinical indications suggest otherwise, a patient with low back or neck pain and a normal thermogram will most likely not benefit from proceeding with a CT scan or myelogram.

This approach reduces radiation exposure and expense, and in the case of a myelogram, avoids an invasive procedure with its possible complications. In addition, it can point the way to other levels of involvement that may be missed on a given anatomic study or that may be masked by a dominant clinical complaint, thus leading to a more complete clinical/physiologic/anatomic investigation. They considered that adequate training as well as proper technique are required for the proper performance and interpretation of these thermograms and to detect artifacts. From this analysis Hubbard et al concluded that thermography has a diagnostic validity at least equivalent to accepted radiologic procedures such as myelography and CT scanning, and a higher negative predictive value than either.

Green et al reported on a retrospective study to assess thermography as a predictor of the outcome of myelography in a group of 80 patients(31). All patients included in the study had first undergone a period of three months of conservative therapy for their symptoms of radiculopathy. The results revealed that negative thermograms were predictive of negative myelograms in 93 per cent of cases. Positive thermograms were predictive of positive myelograms in 71 per cent of patients. The authors suggested that additional studies were needed to assess just how useful the procedure may be in clinical practice.

Frymoyer and Haugh reviewed research performed to establish the reliability of thermography in the diagnosis of low back pain and sciatica(32). They also discussed desirable features of clinical protocols necessary to assess diagnostic accuracy of the test.

The authors found that studies performed up to 1986 time were flawed by a least one and most commonly two or more of the criteria considered important in clinical experimentation protocols. They pointed out that these same criticisms can be made about many of the published studies regarding tests such as myelography and CT. The most common omissions have been the absence of a carefully selected control population, or that the observers were not blinded and, therefore, were subject to observer bias. They concluded that despite current enthusiasm for thermography, in the absence of carefully controlled experiments, the accuracy of thermography in the diagnosis of low back disease must still remain speculative.

In the same year Meeker and Gahlinger provided a review and summary of current research and a comparison of thermography with myelography, CT, EMG and clinical and surgical findings in cases of presumed musculoskeletal pain syndromes(3). The authors concluded that thermography is a promising diagnostic tool for neuromusculoskeletal complaints. It compares favourably with myelography, EMG and CT scans in sensitivity and negative predictive value. Specificity and positive predictive value are not as supported, but compare well. When compared to clinical impression and surgical results, thermography appears as valid as other more commonly used tests. However the authors stated that there are a number of criticisms of current research, including unknown observer reliability, lack of prospective patient controls and descriptions, lack of blinded interpretation of results, and incomplete follow-up of the clinical outcome, which should be addressed in future studies.

The review by the US NCHSR(1) referred to a survey of 406 Fellows of the American Academy of Orthopedic Surgeons conducted in 1987. The survey was undertaken in an effort to find out what orthopedic surgeons who regularly treat neck and back problems think of thermography. Ninety three percent of the 316 respondents to the questionnaire handled neck and back problems in their practice. Thermography was used by only 6 percent. In contrast, 100 percent used x-ray, 99 percent used CT scan, 83 percent used MRI, and 91 percent used EMG. Thermography was thought to be a valid test for neck and back pain by only 5 percent of the respondents. However 52 percent had "no firm opinion" on the matter. Only six physicians using thermography considered it helpful.

To counter criticism for potentially biased interpretation, Uematsu et al used a computer-calculated temperature difference to define the degree of asymmetry that may be observed in patients with functionally impaired spinal roots(33). Temperature differences between lower extremities were measured to compare the degree of thermal asymmetry in 144 patients with low back pain. They found the patients displayed highly significant thermal asymmetries with the involved limb being cooler. When asymmetries exceeded one standard deviation from the mean temperature of homologous regions measured in 90 normal control subjects, the positive predictive value of thermometry in detecting root impingement was 94.7 per cent and the specificity was 87.5 per cent. The authors concluded that in this group of patients thermometric study provides physicians with information for proper decision making and the test can be performed to avoid more invasive and probably less revealing diagnostic or exploratory surgical procedures.

In a 1988 review of back pain and sciatica, Frymoyer states that thermography is a controversial test, and, although it is highly sensitive to peripheral nerve-root dysfunctions, its results in evaluations of acute and chronic sciatica have not been uniform(34). Furthermore the basis for the use of this test in the assessment of chronic low back disability remains unproved. However, Jinkins et al recently examined the pathways of pain mediation and autonomic dysfunction caused by lumbar disc extrusion(35). Frymoyer commented also that the results obtained with the test constitute inadmissible evidence in some courts.

So et al noted that despite the large number of publications on the use of thermography in low back pain, only one attempt to compare patients' data quantitatively to a control group had been reported(8). They noted that the report by Uematsu et al showed an abnormality rate of 85 per cent in patients with abnormal myelographic studies, but used as the criterion for abnormality an interside temperature difference greater than one standard deviation from the normal mean. So et al consider that such a criterion results in an unacceptably high rate of false positives with a single test variable, and the problem being compounded with multiple test variables in the same patient.

So et al studied 27 normal subjects and 30 patients with low back pain to evaluate the diagnostic accuracy of thermography in the diagnosis of lumbosacral radiculopathy(8). Thermographic abnormality was defined as the presence of either interside temperature difference exceeding three standard deviations from the normal mean, or an abnormal heat pattern overlying the lumbosacral spine. In patients with clinically unequivocal radiculopathy, thermography and electrophysiologic study were similar in diagnostic sensitivity, and the two methods agreed on the presence or absence of abnormality in 71 per cent of cases. However, the thermographic findings had limited localizing value. Relative limb warming was often seen in patients with acute denervation on EMG, and limb cooling in those with more chronic lesions, but the side of the root lesion could not be identified confidently by thermography alone. Moreover, thermographic abnormalities appeared not to follow a dermatomal distribution and failed to identify the clinical or electrophysiologic level of radiculopathy in most cases. The authors concluded that the thermographic findings are nonspecific, of little diagnostic value, and of uncertain prognostic relevance. They further commented that the cost effectiveness of the technique had not been defined.

In a recent review of diagnostic imaging procedures for the lumbar spine, Deyo and co-workers noted that thermography is persistently controversial(36). The observation that sciatica nerve irritation may result in higher surface skin temperatures has resulted in the use of thermography of the lower extremities. They noted that published comparisons between thermography and other imaging procedures have been small and poorly designed and have yielded conflicting conclusions. The authors concluded that further study is necessary to establish the added value, if any, of this procedure over more direct imaging of the spine and discs.

A recent article reported on a prospective study by Thomas and coworkers of 65 people with chronic back pain and sciatica where IR thermography was compared with MRI, CT, myelography and discography(37). They found close correlation between these different investigations. Thermography showed abnormalities in 92 per cent of cases, MRI in 89 per cent, CT in 87 per cent and myelography in 80 per cent. Thermography results correlated with MRI in 89 per cent of cases and with CT in 87 per cent. They were able to show significant sympathetic response in 18 cases with lumbar disc pathology and non-radicular referred pain where MRI, CT and myelography analyses did not show any nerve root involvement.

The Subcommittee of the AAN in its assessment of thermography noted that the technology has been reported to be useful for the detection of cervical and lumbar nerve root irritation and compression(24). The Subcommittee, based on the current scientific and clinical information, found that thermography probably is not needed in many cases of neck or back pain suspected to be associated with nerve root irritation or a compressive lesion caused by a disk or tumour. The test probably is not indicated for patients who have mild or short-lived neck or back pain with neurologic findings and who will not be considered for surgical treatment. It is not necessary either for patients who have obvious clinical radiculopathies requiring the more definitive studies of CT, MRI, or myelography. Thermography may provide characterising information in those cases in which it would be helpful to know whether nerve root or segmental nerve is or is not affected and confirmation of involvement is needed. Compared with EMG, it provides less information about localisation and pathologic events. Compared with CT, MRI, or myelography, thermography provides less localising and diagnostic information. Based on current information, the Subcommittee does not support the use of thermography as a screening test for patients with neck or back pain.

Neuromuscular – compression and entrapment neuropathies

Damage to a peripheral nerve by pressure results in a compression neuropathy. This may occur at any point along the course of the nerve, although there are certain sites where individual nerves are anatomically vulnerable. The source of the pressure may be external, such as an ulnar neuropathy resulting from habitually leaning on the elbow. Entrapment neuropathies are specific forms of compressive neuropathies that occur where the nerves are normally confined to narrow anatomic passageways and therefore are susceptible to constricting pressure. Compression of the median nerve within the carpal tunnel is the most common entrapment neuropathy.

In entrapment neuropathies localised pain is a common complaint, often occurring at rest, but the pain may also radiate or be referred to other sites, some at considerable distances from the damaged nerve. The symptoms of sensory nerve dysfunction, such as tingling, numbness, burning, and other paresthesias are, unlike the pain, usually confined to the cutaneous distribution of the nerve.

Many tests have been devised to try to diagnose these neuropathies. Nerve conduction studies are of use in the localisation, assessment of severity, and management. Other tests include EMG, nerve percussion and wrist flexion(38). Stewart and Aguayo have provided a useful description of the neuropathies, their sites and clinical evaluation(38).

Thermography has been presented as a viable alternative in the diagnoses of acute and chronic compressive neuropathies(39). However, the thermograms obtained may be difficult to interpret because the results of partial injury to peripheral nerves are at times difficult to predict. Initially, the damaged nerve segment of the skin may be warmer (usually for the first few months) and then become cold. Sometimes initial warmness may rapidly return to normal temperature(22,40).

Herrick et al performed thermographic examinations on 92 patients with extremity pain using LCT and IR thermography[41]. The purpose of the study was to diagnose carpal tunnel syndrome (CTS) and to differentiate between CTS and other peripheral neurovascular injuries. All electrodiagnostic studies were done by the same neurologist and all patients were examined by the same orthopedic surgeon who interpreted the LC thermogram. An experienced outside reader interpreted the infrared images.

Results of clinical examinations were used as the standard against which thermographic and electrodiagnostic studies were compared. Thermal patterns of CTS were characterised by a temperature decrease over the median nerve distribution. When LCT was used, sensitivity was 98 per cent and specificity 90 per cent. IR thermography resulted in a 95 per cent sensitivity and 89 per cent specificity. In contrast, sensitivity of EMG/nerve conduction studies was 35 per cent with specificity of 100 per cent. They noted that when EMG/nerve conduction studies were positive there was 100 per cent correlation with thermographic findings. The authors suggested that the thermographic technique may lead to early diagnosis, treatment and preventive measures which would avoid the high cost of manpower loss and medical care often concomitant with CTS.

In a later study of 90 patients with CTS, Herrick and Herrick reported the overall sensitivity of thermographic studies was 96 per cent and the specificity was 80 per cent[39]. However So et al commented that that study had no control group and the thermographic and clinical criteria for diagnosis were inadequately specified[40].

Meyers et al reported on a recent quantitative evaluation of thermographic findings in electrophysiologically proven CTS because they noted that several previous authors had reported favourable results with thermography in CTS without quantifying their findings and including data on control series[42]. They performed LCT in 38 normal hands and in 23 hands with CTS documented by nerve conduction studies (NCS).

For each hand, seven temperature measurements were performed at the tip of each digit and in the centre of the thenar and hypothenar eminences. Statistical comparisons of temperature differences between each of the seven selected sites between the patient and control groups were obtained. The thermogram readers were blind to the nature of the data (control or CTS). The results revealed no significant thermographic abnormalities in nine cases of CTS with mild electrophysiologic abnormalities. Out of 14 CTS hands with definite electrophysiologic abnormalities, only seven hands (30 per cent) revealed unequivocal thermographic changes by quantitative studies. They concluded that the results indicated the low sensitivity of LCT in CTS and suggested that thermography would not be useful in the diagnosis of CTS with equivocal or absent electrophysiologic abnormalities. They also commented that previous favourable reports concerning thermography in CTS may have been due to lack of control series or absence of quantification.

In response to this report Herrick suggested that the procedures and methods used were not sufficient to allow the authors to reach the appropriate conclusions[43]. Herrick's critique has been answered by Cros and Meyers and a difference of opinion remains[44].

So et al compared the diagnostic accuracy of IR thermography with that of conventional electrodiagnostic studies in 22 patients with CTS, 15 with ulnar neuropathy at the elbow and 20 normal subjects[40]. They found abnormal thermograms in 55 per cent of patients with carpal tunnel syndrome and 47 per cent with ulnar neuropathy, using 2.5 standard deviations from the normal mean as criteria for abnormality. The abnormalities consisted of either an increase in interside temperature difference in the fingers and hands or an alteration of the normal thenar-hypothenar temperature gradient in the fingers. The sensitivity of thermography was considerably lower than that of conventional electrodiagnostic methods. Moreover, the thermographic abnormalities were nonspecific, and could be misleading as they did not reliably identify the side of lesion or distinguish between median or ulnar nerve involvement. They concluded that thermography was not helpful in the diagnosis of these two common entrapment neuropathies.

This report drew criticisms concerning how the study was undertaken and how the results were interpreted from Wexler(45), Gross(46), and Uricchio(47). A detailed response was published by Aminoff, So and Olney, reflecting the disagreement in the usefulness of thermography(48). The criticisms by Uricchio extended beyond the paper to the policies of the journal, suggesting a conspiracy to discredit thermography(47).

In reply to the comments by Uricchio, the Editor-in-Chief of the journal stated that as the study has important implications for clinical practice, the publication had been expedited(49). He further commented that evidence that a widely used diagnostic test was deemed valueless was information that should be disseminated expeditiously in an effort to conserve unnecessary health care expenditures.

A recent statement by the Royal Australasian College of Physicians concerning RSI (repetitive strain injury) commented that thermography does not add to the clinical diagnosis and its use as a medico-legal tool is not recommended(50).

In the assessment of available scientific and clinical literature the Subcommittee of the AAN found that the use of thermography in the assessment of entrapped nerves is not promising(24).

Neuromuscular – Reflex sympathetic dystrophy (RSD) syndrome

Reflex sympathetic dystrophy (RSD) is a clinical syndrome characterised by pain, dystrophic tissue changes and local disturbance of autonomic function in a limb or part of a limb. Trauma is the most commonly identified precipitating event.

The diagnosis of RSD traditionally has been based on the physical finding of vasomotor change, sudomotor (sweat) dysfunction, changes in the temperature of the skin, stiffness of the joints, and swelling combined with pain(51). Thermography is being used to document the changes in temperature associated with RSD and the diagnosis of this condition is considered as one of its most important applications (Cassar, personal communication).

Hendler et al undertook a study designed to determine the percentage of patients complaining of chronic unexplained pain who had received an inappropriate psychiatric diagnosis because they had only the subjective symptoms of pain(52). A total of 224 consecutive patients were studied, all of whom had been referred for evaluation of "psychogenic" pain. Attempts were made to identify any underlying disease related to the presence or absence of RSD.

Determination of RSD was made when a positive thermographic evaluation corresponded with the area in which pain was subjectively reported. Abnormal thermograms in the affected limb (a reduction in temperature of 1°C or more) were found in 43 of the patients (19 per cent). Thirty two cases were thought to have RSD. Of those, only five could be shown to have correlative EMG test results. The authors stated that thermography often draws a map of the area of pain. Furthermore, the technique has a value in qualitative and quantitative evaluation of sympathetic function after sympathetic block or sympathectomy. It documents whether the appropriate ganglions were blocked or surgically denervated. They suggested that the use of thermography often improves the results of sympathectomy, since good outcome depends heavily on accurate diagnosis.

In a recent study of LCT thermography in the evaluation of post-traumatic pain to the spine and extremities, Pochaczevsky evaluated 70 patients and found that 70 per cent had thermographic abnormalities compatible with nerve fibre irritation(53). No control patients were included in the study. He considered that thermography was of value in establishing the presence of physiologic abnormalities in these patients, as all had roentgenograms reported as normal or as showing no evidence of acute injuries. However, thermographic findings were completely normal in the remaining 30 per cent of the cases.

Cooke et al measured the temperature response of the hands to mild cold stress (20°C for one minute) in 20 normal subjects, 20 patients with RSD and 10 with chronic upper limb pain (CULP)(54). IR thermography was used to measure spatially averaged hand temperature. The results of the RSD and CULP groups were significantly different from the normal group but were indistinguishable from each other. The authors concluded that the thermal stress test is useful in the objective assessment of RSD.

The review by the US NCHSR of thermography stated that there had been two recent reviews of RSD, neither of which referred to thermography in its diagnosis(1). The first review maintained that the diagnosis is primarily clinical and that the best approach to confirm its presence is the use of differential blockade. These reviews referred to radiologic changes that are important in the recognition and diagnosis of RSD and suggest the use of scintigraphy for both diagnosis and management.

A more recent review of pain dysfunction syndromes stated that the test that establishes the diagnosis of RSD beyond reasonable doubt is the response to sympathetic blockade. If a patient who is thought to have sympathetic dystrophy does not respond to treatment that eliminates sympathetic inflow, the diagnosis is in question(51).

The review noted that three-phase bone scans, measurement of vasomotor or sudomotor reflexes and thermography are three currently available methods that can contribute objective data for the establishment of the diagnosis of RSD.

Thomas (personal communication) has advised that a published consensus of experts on RSD in 1989 includes the statement that thermography is the autonomic diagnostic test for this condition(55).

Ignacio et al described the use of infrared imaging in the diagnosis and treatment of 12 patients with RSD following neuromuscular and skeletal injuries(56). All patients had unequivocal evidence of RSD; positive findings on clinical examination included persistent burning pain, swelling, edema, hyperesthesia, hyperhydrosis, vasomotor instability, trophic changes and/or joint contractures. Diagnostic evaluation included serial X-ray examinations, electrodiagnostic studies (EMG and nerve conduction velocities) and thermography.

Eleven patients received a series of sympathetic stellate ganglion nerve blocks; one patient received a lumbar sympathetic nerve block. An experienced anesthesiologist performed all sympathetic blocks as an in-and-out operating room procedure under continuous thermographic monitoring. Baseline thermograms were obtained prior to performance of the sympathetic nerve block, and thermographic monitoring was continued up to 15 minutes following injection of local anesthetic.

Clinical evidence of successful stellate ganglion block includes reduction of pain and hyperesthesia, increase in active and passive motion, reactive vasodilatation with reversal of limb coldness, and Horner's syndrome. A reversal of the abnormal sympathetic neural activity is documented by thermographic evidence of a temperature increase of at least 3°C in the involved limb and the face. This initial response is noted as early as one minute following nerve block.

Electrodiagnostic studies were abnormal in seven patients; two of this group had radiculopathies while five had peripheral nerve entrapments. In all patients, thermographic examinations confirmed the diagnosis of RSD, although the magnitude of thermal discrepancy did not always correlate with the severity of pain, swelling and immobilization. Continuous thermographic monitoring of all 12 patients demonstrated a satisfactory physiologic response to sympathetic nerve block.

The authors concluded that thermal imaging in RSD provides an objective, quantitative means of evaluating patient response to a wide variety of treatments. In addition to its validation of the effectiveness of sympathetic nerve block, dynamic intra-operative thermographic monitoring introduces a new dimension for demonstrating the sequence of neurophysiologic responses to sympathetic nerve block.

Coughlan et al examined 33 patients with undiagnosed chronic knee pain with features of autonomic disturbance(57). All patients had radiographs of both knees and infrared thermography was performed on each leg. The mean duration of pain was 3.4 years. Sixteen normal controls were used in the study. Patients with local lesions were excluded from the study. Thermal asymmetry was shown in patients with knee pain but was not present in controls. The link between the pain and this feature of sympathetic dysfunction was confirmed by the return to normal symmetry in patients whose pain completely or almost completely resolved. In the other patients with persisting pain the thermal asymmetry persisted. On the basis of these features a diagnosis of RSD could be made. The authors concluded that RSD is an important cause of chronic knee pain. In patients with undiagnosed knee pain, they considered that attention should be paid to the presence of bone tenderness and local autonomic disturbance, particularly cooling, as a feature that might suggest this diagnosis. Thermography was found to be a useful imaging technique for demonstrating this abnormality.

The review by the US NCHSR(1) noted that the only blind, controlled study of thermography that evaluated patients with chronic pain was that of Sherman and associates(58). They reported on the analysis of 125 patients referred for studies of back, patellar, and phantom limb or body pain. Thermograms of the painful areas were compared with adjacent and nonpainful contralateral areas. Analysis of pattern variation and stability of thermograms was performed on 32 healthy controls. The study concluded by stating that because of the number of false-positive and false-negative findings encountered, further controlled, blinded studies would have to be conducted before thermography could be accepted as a way to demonstrate that a patient has abnormalities related to pain in a particular area.

In relation to peripheral nerve injury the Subcommittee of the AAN found that thermography is not a primary evaluative technique for the detection and diagnosis of peripheral nerve lesions(24). It may be useful as a adjunctive procedure for characterising peripheral nerve injury and RSD. Although thermography may be sensitive to the detection of RSD, the Subcommittee considered it is not diagnostic. Further its use in detection and characterisation of polyneuropathy is not established.

Neuromuscular – Myofascial pain syndromes

The existence of myofascial pain syndrome is controversial(4,11). Nevertheless' there has been a recent surge of clinical interest and research activity relating to myofascial pain syndromes due to trigger points(59). Simons and Travell have provided a useful review of myofascial pain syndromes, their signs and symptoms, location, aetiology, diagnosis and treatment(60). Recent studies indicate that myofascial pain syndromes are a far more common cause of both chronic and acute musculoskeletal pain that is generally recognised. Simons has summarised the recent research advances in this area(59).

Myofascial trigger points are hyperirritable foci located within taut bands of skeletal muscle, ocurrring at a characteristic location within a given muscle (61). A trigger point (TrP) is easily located by palpation and other objective signs.

The diagnosis is suspected when the onset of pain is associated with muscle strain and when the patient's distribution of pain fits known myofascial pain patterns. A presumptive TrP is located by the restricted range of motion and slight weakness of the muscle, and by palpating a tender spot in a tense band of muscle. A TrP is confirmed when pressure on it produces at least part of the patient's pain pattern, or when a specific transient pressure stimulus produces a local twitch response of the muscle fibres that harbor the TrP. Myofascial syndromes are treated by specific myofascial therapy using passive stretch during vapocoolant spray, ischaemic compression and hot packs.

Techniques have been developed to document the condition to enable evaluation of progress and treatment effectiveness. Two methods described recently involve pressure threshold measurements and thermography (61).

In the course of evaluating over 250 patients with pain symptomatology attributed to the cervical region, Weinstein reported the development of a reproducible technique using thermography that enabled the establishment of the presence or absence of trigger point pathology (62).

Simons reviewed the literature and noted that early human thermographic studies stated that myofascial pain is associated with disc-shaped hot spots that are 5 to 10cm in diameter and located over the TrP(59). Whether the hot spot actually lies over the TrP or over the referred pain was unclear from the literature. Some papers avoided the issue. Other papers indicated that a reduced pressure threshold reading at the hot spot means it is a TrP. However, the local tenderness could also be due to referred tenderness in the reference zone of a TrP. Other papers specifically relate the hot spot to the area of pain complaint, which is usually in the zone of referred pain, and not at the TrP. The referred pain zone is variously identified as cold, as cold or hot, and as hot.

Simons concluded that thermographic changes can often (but not always) substantiate active myofascial TrPs that have been identified by history and physical findings. He considered that thermography's potential for exploring the cutaneous autonomic phenomena associated with myofascial TrPs remained essentially untapped.

The potential sources of errors in detecting triggers points and the difficulties encountered in imaging curved body surfaces have been discussed earlier in this report(11).

Vascular - deep vein thrombosis

The diagnosis of deep venous thrombosis (DVT) is difficult on clinical grounds alone. Physical examination for the evaluation of DVT has been shown to be unreliable and contrast venography has remained the standard diagnostic method. However venography is both expensive and invasive with risks associated with the use of contrast material including allergy, renal dysfunction and venous thrombosis. As a result, there have been many attempts to develop simple, less hazardous, alternative approaches to confirm the presence of clinically suspected DVT. These include plethysmography, duplex sonography and thermography.

Pochaczevsky et al compared LCT and ascending phlebography in the study of 30 patients with the clinical diagnosis of DVT(63). Thermographic interpretation was based on the findings of Cooke and Pilcher who reported that increased temperature in an extremity and its delayed response to cooling are signs of DVT. Pochaczevsky et al reported that their preliminary results showed excellent correlation with ascending phlebography. The two methods were in agreement in 90 per cent of cases with no false-negative thermograms. The authors concluded that the technique showed promise as a non-invasive screening study for the diagnosis of DVT in high risk patients.

In 1981 Aronen et al reported on their study designed to evaluate the capacity of infrared thermography to reduce the number of conventional phlebographies(64). They noted at that time that the method had not been generally applied in routine work. Their case subjects comprised 141 unselected consecutive ambulant patients with suspected thrombosis or insufficiency of the perforant veins in the lower extremity. Their results showed that thermography was useful in the diagnosis of deep thrombosis and is capable of replacing about half the phlebographies otherwise needed in suspected thrombosis.

However, patients with previous diseases of the leg veins such as insufficiency of the perforant veins and post-thrombotic changes, often show misleading signs on thermograms. In these cases, phlebography or other methods are needed. They recommended thermography for the primary investigation in suspected deep thrombosis. If the finding is negative, the presence of thrombosis is highly unlikely. The cases with positive findings require a confirmation with other methods because of the nonspecificity of a positive thermogram. They commented that this order of investigation reduces both costs and hazards in the diagnosis of DVT.

Sandler and Martin have compared the accuracy of LCT and clinical examination was compared with that of X-ray venography in 80 patients clinically suspected of having unilateral, lower-limb, DVT(65). The clinical examination was not helpful in diagnosis. Of the 35 patients with confirmed deep-vein thrombosis, 34 had a positive thermogram, giving a sensitivity of 97 per cent. 17 false-positive thermograms gave a specificity of 62 per cent. The predictive value of a negative thermogram was 96.5 per cent. They concluded that thermography is a quick, inexpensive, non-invasive investigation that might be useful as a screening test in patients suspected of having unilateral, lower-limb, deep vein thrombosis. They considered that a diagnostic scheme starting with liquid crystal thermography and followed by a venoscan, involving the injection of technetium-99m-labelled fibrinogen and gamma imaging of venous flow, venous pool and fibrinogen adherent to the thrombus, might obviate the need for X-ray venography in almost 80 per cent of patients with suspected deep-vein thrombosis.

More recently Leung, Gallus and Sage, compared thermography with ascending venography in patients with clinically suspected venous thrombosis(66). To overcome the highly subjective nature of interpretation of temperature distribution patterns over the areas studied, the authors used a newly developed thermographic scanning device, which automatically compared the temperature profiles obtained by moving a heat sensitive probe along the legs of patients with suspected DVT. Eighty consecutive patients were evaluated and venograms were read independently of knowledge of the thermography result. The authors commented that thermographic scanning is an apparently attractive alternative to venography for the diagnosis of clinically suspected venous thrombosis, since it is simple, painless, quantitative, portable, quick and harmless, and requires little staff training.

However, it is unsuitable for use in about 40 per cent of patients who present with clinically suspected venous thrombosis, because they have clinically recognisable causes of elevated skin temperature other than deep leg vein thrombosis (including superficial phlebitis, extensive varicose veins, trauma or recent surgery to the legs and cellulitis, which could be responsible for a 'false-positive' thermographic result. In these patients the specificity of thermography for DVT (19 per cent) is far too low for the test to be clinically useful.

In the 60 per cent of patients who have no recognisable source of 'false-positivity' they found the specificity of thermography for DVT to be acceptable (nearly 90 per cent), but its sensitivity to DVT was suboptimal, since thermography failed to detect nearly 25 per cent of venographically demonstrable deep leg vein thrombi, regardless of whether these were limited to the calf, or involved the popliteal, femoral or iliac veins ('proximal' DVT).

Leung et al concluded that a diagnostic method which fails to detect about 25 per cent of 'proximal' DVT is too insensitive to be used alone as a basis for therapeutic decisions in patients with clinically suspected venous thrombosis, since untreated 'proximal' DVT carries a high risk of further extension and embolism.

On the other hand, their initial evaluation suggested that thermography may have a limited diagnostic role. Its high specificity in the absence of recognisable causes of 'false-positivity' suggests that an abnormal thermographic scan in such patients could be used as a basis for anticoagulant treatment. A negative result, on the other hand did not exclude clinically significant thrombosis, and should therefore be followed by another, more sensitive but more complex, non-invasive test (such as plethysmography), or by venography.

In 1989 Free and Faerber reported on their evaluation of the use of LCT as a screening tool in the detection of DVT(67). Forty patients were examined with LCT and venography. The venogram was used as a standard of comparison for the results of the thermogram which was interpreted independently. The results of the evaluation showed that LCT had a sensitivity of 70 per cent and a specificity of 50 per cent. The authors concluded that, even though the study was somewhat limited by the relatively small number of patients, LCT was found not to have a greater accuracy than clinical examination.

In a study of 56 patients with total hip replacement, LCT was used to screen for DVT, using bilateral ascending phlebography as the reference procedure(68). Examinations were performed on the seventh postoperative day and all thermograms were evaluated blindly and independently at the end of the study. Phlebography revealed unilateral DVT in six patients. Only two had corresponding findings at thermography, giving four false negative results. Moreover, 14 false positive thermograms were found. Based on the number of legs investigated, the sensitivity and specificity were 33 and 87 percent, respectively. The authors concluded that contact thermography is of no value as a screening test for DVT following major hip surgery. They also commented that they were not able to confirm the indication of previous reports concerning the universal applicability of contact thermography for detecting DVT in the lower limbs(68).

In response to an article by Rosner and Doris concerning the diagnosis of femoropopliteal venous thrombosis using duplex sonography and plethysmography(69), Pochaczevsky commented that, unlike those two techniques, LCT is highly sensitive in this diagnosis(70). The predictive value of a negative thermogram is more than 96 per cent and, if the thermogram is negative, the results of venography are, as a rule, also negative. Additionally LCT is a noninvasive, relatively inexpensive, simple test that is, generally, not operator dependent and can be performed at the bedside. In reply Rosner stated that as a screening technique, it is similar to plethysmography in that it has high sensitivity while sacrificing specificity(71). Because it is an indirect technique, it is subject to physiologic alterations that can produce false positive examinations. He noted that Sandler and Martin found only 62 per cent specificity, with 17 false positive examinations(65). Therefore, anticoagulation therapy should not be started on the basis of a positive thermogram.

Rosner found thermograms somewhat complex and considered that interpretation may be associated with a long learning curve and or interradiologist variability, which, he considered, may in part, explain why thermography has not gained popularity. At his centre, duplex sonography has become the primary diagnostic technique for evaluation of femoropopliteal thrombosis, largely replacing contrast venography(71).

Kotzmann and the RACR (personal communications) hold the view that thermography may be used as a noninvasive screening test for DVT of the lower limbs. However there are many false positives, and the advantage of the test is that the false negative rate is low. Positive results are an indication for more invasive investigation such as venography. They therefore conclude that there is a place for this technique as a screening test for DVT, and as such it is probably more sensitive than Doppler ultrasound and isotope studies.

However, recent reports tend to support the use of Doppler ultrasound as the investigation of choice for the diagnosis of DVT(72,73).

Vascular – facial

The diagnosis of headaches based on clinical examination has often presented difficulties. As a consequence many workers in the field have endeavoured to identify a number of "markers" that could represent objective criteria for diagnosis and monitoring of the condition.

Rapoport et al attempted to define consistent facial thermographic criteria corresponding to different headache diagnoses in 100 patients and compared them with controls(74). All patients were free of vascular headache at the time of thermography. They found that the migraine group had significantly more cold noses than the cluster headache group. Thermograms of cluster headache patients were asymmetric significantly more often than those of migraine headache patients. Overall cluster patients showed increased blood flow in the distribution of the external carotid and decreased blood flow in the distribution of the internal carotid artery.

Drummond and Lance studied thermographically the time course of extracranial vascular changes in 11 patients during cluster headaches and in 22 during attacks induced by nitroglycerin or alcohol(75). A secondary objective was to study clinical and thermographic responses to oxygen inhalation. The authors found that heat loss from the affected orbital regions of the face increased during cluster headache and in some patients spread above and below the eye, down the nose, and to the affected temple. Inhalation of 100 per cent oxygen reduced or abolished cluster pain in 22 of 25 instances, and asymmetry of heat loss then disappeared. They were uncertain whether oxygen acted directly on dilated blood vessels to terminate the attack or had an indirect neural effect.

Kudrow in 1985 reported on a thermographic study of 650 patients during non-headache states(76). He found an asymmetric, ipsilaterally decreased supraorbital temperature distribution in 67 per cent to 75 per cent of patients with cluster headaches, classical migraine and hemiplegic migraine. He also noted a specific contralateral thermographic pattern (described as a "chai" pattern) that occurred with significantly greater frequency in the cluster headache group when compared to the combined classical and hemiplegic migraine groups.

Swerdlow and Dieter used thermography to study 275 headache patients and 45 headache-free subjects to determine if thermograms could serve as a reliable marker for vascular headaches(77). Their statistical analysis suggested that the presence of "cold patches" (regions of the face more than 0.5°C cooler than surrounding areas) may be a valid discriminator between vascular, cluster, and muscle contraction headaches. However, the US NCHSR review noted that an editorial at that time in 1986, emphasized that the diagnoses were based on the subjective assessments of one clinician, the numbers in some diagnostic categories were small, and there was a need for these results to be confirmed in other laboratories with more patients before thermography is considered a useful marker for vascular headaches(1).

In 1988, Volta and Anzola noted recent evidence that in both classic migraine and in cluster headache, on thermography, a "cold patch" ipsilateral to the prevailing side of pain could be detected in virtually all patients in the interictal phase(78). They studied the temporal course of this characteristic thermographic pattern together with the use of visual evoked potentials, in 32 consecutive patients with headache. They concluded that although the preliminary data were obtained from a small sample and without the support of inferential statistics, thermography and visual evoked potentials seemed to be useful objective criteria for monitoring the course of some primary headaches.

The Subcommittee of the AAN, in its assessment of thermography, noted that the technology is being used to study vascular phenomena associated with headache(24). It also noted that cluster headache has been reported to be associated with characteristic thermographic pattern in approximately two thirds of the patients. Because cluster headaches are diagnosed by characteristic symptoms and absence of neurologic abnormalities, the Subcommittee did not beleive that thermography is sufficiently useful to become a standard evaluative procedure in cases of headache.

Pogrel et al noted that thermography has been used in a variety of maxillofacial conditions including temporomandibular joint problems and tumour detection(79). They commented that, although claims had been made for this method of monitoring, it had never achieved a degree of popularity, probably partly because of its lack of specificity and cost. They undertook a study to detect normal skin temperature and relate them to thermograms with a variety of conditions of the temporomandibular joint as well as those from patients with myofascial pain dysfunction syndrome. Pogrel et al found in general that skin temperatures in normal volunteers are not constant from day to day and vary in response to a number of stimuli, but that some information may be determined by comparisons of different sides of the same patient on the same day. There seemed to be some differences in patients with temporomandibular joint dysfunction and possibly in patients with large necrotic tumours. They concluded that although thermography may have clinical applications, such wide variations in normal values were noted that any standardisation was extremely difficult.

In a recent pilot study Gratt et al evaluated the potential of thermography as a diagnostic aid in dentistry(80). The study assessed thermal symmetry of the face and neck in 20 normal subjects with the use of frontal and lateral views at 1.0°C and 0.5°C sensitivity, under controlled conditions. They found, in general, normal subjects demonstrated high levels of thermal symmetry over most regions of the face. They concluded that thermography has potential for use as an alternative diagnostic technique in dentistry.

Vascular – vasospastic disease

Vasospastic disease is characterised by digital vasospasm or episodic constriction of digital arteries and an inability to cope with cold. Ring and collaborators have evaluated Raynaud's phenomenon (a vasospastic disease) using thermography(81). They noted that in normal subjects thermal recovery after thermal stress (e.g. cooling the hand to 20°C in an ambient temperature of 24°C) follows a well-defined pattern and takes place much faster than in vasospastic subjects (eg 4–12 minutes as opposed to 15–60 minutes).

They suggested that under standard conditions, extended recovery times may be used to characterise different degrees of vasospasticity. In certain cases, thermal recovery of the dorsum of the hand occurs in the absence of recovery in the fingers. However in most cases, a normal thermal recovery pattern can be used to exclude a vasospastic condition. But the absence of a normal responce in one or more fingers should be carefully evaluated for possible underlying causes and repeated tests done to confirm the result. They concluded that the thermal pattern in the hand of a vasospastic subject may not differ from that of a normal subject until stress is applied.

In an earlier publication Ring et al commented that the cold water stress test for detection of vasospastic disease in the hands seems to have been evaluated enough to enable its use in clinical trials(82). The evaluation of Raynauds Phenomenon by thermography in conjunction with a stress test is used by a number of centres (Ring, personal communication).

Applications of thermography in other vascular disorders include subclavian vein thrombosis and diabetic arteriopathy, neuropathy and ulceration (Australian Society of Thermology, personal communication). However recent reviews of the many tests for autonomic function and for diabetic autonomic neuropathy have not mentioned thermography(83,84,85).

Oncology – breast lesions

Thermography as a means of detecting cancer in the breast has been a controversial technique. The rationale for its use was based on the belief that carcinoma of the breast is a vascularised hypermetabolic lesion, whose temperature increases with the level of its malignancy(86). Despite initial positive reports it became apparent that heat abnormalities were not always present with malignancy nor always absent in non-cancerous breasts (87).

In 1983 US NCHSR reported on a review by the National Cancer Institute of clinical studies which the Institute sponsored to determine the value of IR thermography in breast cancer diagnosis(12). It was noted that the application of the technology in this application was controversial. The following year the use of thermography for the detection of breast disease was excluded from US Medicare coverage.

In 1984 the American College of Radiology issued a policy statement on thermography for the detection of breast cancer (88). The statement advised that thermography was still an experimental procedure with no established clinical indications. The clinical use of breast thermography should be restricted to properly controlled prospective studies designed to evaluate clinical efficacy.

A review by Mushlin(87) of the results from published series and a position paper by the American College of Physicians(89) concluded that, from the standpoint of screening, thermography could not be advocated. Its lack of sensitivity, combined with a high percentage of the false-positive results, makes it ill-suited for this use, despite the advantage of no radiation exposure or potential risk.

Stevens and Beaman recently assessed the potential of thermography as a screening technique for the early detection of breast cancer using a mathematical model to isolate and quantify the vascular contents of breast thermograms(90). In a retrospective study, 45 patients found to have breast cancer and 49 patients who developed breast cancer within five years of being screened were compared with 45 patients who were found to be normal on examination and had still not presented with breast symptoms five years later. No statistically significant separation was resolved between either of the paired groups, implying that the vascular content of isolated thermograms is unable to provide meaningful indications of breast cancer.

Isard et al reported on their experience with a small (70 patients) but well-defined group of patients, all of whom had breast thermographic evaluation done at the same time as the establishment of a definitive diagnosis of breast cancer(91). A prognostic classification for thermographic staging of breast cancer was applied to the patients who were followed for a minimum of six and a maximum of 13 years. Survival rates for those with favourable, equivocal and poor thermographic factors were compared with each other and with results in accordance with tumor-node-metastasis (TNM) classification. They found that the thermographic scoring system showed shorter survival for patients with poor thermographic prognostic factors. They concluded that although the numbers reported were small, the results tended to support the usefulness of the imaging test as a prognostic indicator for survival and continued investigation appeared warranted in order to collect, follow and correlate larger series of cases.

Ciatto et al reported on a study of 4,624 non-cancerous women who had undergone IR thermography from 1976 to 1983(92). The purpose of the study was to assess the association between thermography pattern and risk of subsequent breast cancer in otherwise clinically normal patients. Thermography was not performed as a routine test but in selected patients on the basis of a questionable report on physical examination, mammography or fine needle aspiration cytology. The authors concluded that thermography did not show any practical role as a breast cancer risk indicator.

Williams and co-workers recently reported on their study designed to determine the specificity and sensitivity of thermography as a screening test for breast cancer and to show whether or not it could be used to identify women at high risk of developing the disease within five years(93). A total of 10,238 women aged between 40 and 65 had a thermographic and clinical examination of their breasts. If either examination was abnormal they were referred for mammography. Sensitivity of thermography was found to be 61 per cent and specificity 74 per cent. A documentary follow-up of each women was conducted five years later, when it was found that 71.6 per cent of the women who developed breast cancer had had a normal thermogram at the time of examination, as did 73 per cent of those who did not. The report concluded that thermography is not sufficiently sensitive to be used as a screening test for cancer, nor is it useful as an indicator of risk of developing the disease within five years.

Ulmer, Brinkmann and Frischbier noted that the literature concerning thermography within the framework of post therapeutic care following breast-conserving therapy (tumorectomy and subsequent radiation therapy) frequently suggests that a recurrence in the treated breast could be diagnosed by rising breast temperatures much earlier than other diagnostic tools(94). They designed a study to assess the value of thermography in the post-operative follow-up of patients treated in a breast-conserving way. IR thermographic data of a prospective study of 309 women after breast-conserving therapy were evaluated. Nineteen of the women had an intramammary recurrence. Thirteen recurrences were ascertained within the first five years after the initial operation, one after six years, and five after nine to twelve years. Ulmer et al found that the thermographic behavior of the breast after breast-conserving therapy is not uniform and that the thermographic data of women with evidence of intramammary recurrence show no significant difference from those without recurrences, neither at the time recurrence was diagnosed nor with respect to an early diagnosis (at the examinations six months before the actual detection). They concluded that thermography is of no value in the care of patients after breast-conserving treatment

In a recent review of nonmammographic breast imaging techniques, Kopans did not mention the use of thermography(95). A publication, The Surgical Clinics of North America has summarised the most contempory aspects of breast cancer management as of 1990(96). In that issue, Bassett et al noted that despite 33 years of investigation of thermography for the detection of breast cancer, its use continues to be controversial(96). They commented that most small nonpalpable lesions do not demonstrate increased heat and that most women with more heat in one breast than the other have no cancer. They referred to the American College of Radiology statement that the use of thermography in screening is not cost effective and should not be part of the basic screening process.

Kotzmann and the RACR (personal communications) hold the view that there appears to be no longer indications for breast screening with thermography, although some research work recently suggests that by using sophisticated computer models, the accuracy may equal that of X-ray mammography. They consider that this technology may become a viable technique again for breast screening for cancer.

A recent report by the Australian Institute of Health on screening mammography technology noted the poor results obtained using thermography to diagnose breast cancer(97).

Rheumatology

Inflammation of the joint may arise from a number of clinical conditions. The inflammatory process is normally accompanied by a rise in temperature in the affected area and this may provide a useful measure of the activity of the process when sufficiently near to the body surface to influence skin temperature(10). It is reported that thermography has been employed in the study of inflammatory rheumatic disease, rheumatoid arthritis, all forms of polyarthritis and ankylosing spondylitis(10,98). Ring (personal communication) has stated that thermography is used in rheumatology in Europe and Japan

In 1973 a thermographic index was devised which under controlled conditions has a predictable normal range, with elevated values relating to the severity of the inflammation(98,99).

The index has been used to monitor patients with peripheral joint arthritis as well as following the effects of anti-inflammatory drugs (98,99). Recently, Holsbeeck et al compared the utility of sonographic parameters, synovial thickness and intra-articular fluid with the clinical and thermographic noting systems in 20 patients both before and during treatment of rheumatoid arthritis of the knee(100). They found that the thermographic peak asymmetry showed good correlation with clinical status, but the thermographic index was unreliable.

Tennis elbow is one of the commonest lesions of the arm(101) and it has been suggested that thermography may prove useful in clinical diagnosis in the small percentage of patients where diagnosis is uncertain, particularly where patients are seen in the early stages of the condition(102).

Darton and Black have suggested that the use of IR thermography as a diagnostic and monitoring tool in rheumatology has been held up because of the expense of available scanners and the seeming necessity for a temperature controlled room in which to conduct thermographic tests(103). They considered that the development of a relatively inexpensive and portable pyroelectric vidicon thermographic system largely answers the first issue. They noted that the majority of hospital wards are kept at a constant temperature and might provide a sufficiently stable thermal environment for useful clinical records to be obtained on site. Their results of a series of cold challenges to the hand, repeated on a normal subject in a temperature controlled room and in other parts of a rheumatology ward, show very good reproducibility outside the temperature controlled room, provided that the immediate environment is draught free. They conjectured that this fact and the portability of the system enabled it to be taken to the bed sides of non ambulant patients, and may increase the potential use of this simple, cost-effective, non-invasive technique in rheumatological and other settings.

The Australian Rheumatology Association (personal communication) has advised that its South Australian Branch is preparing a report regarding the efficacy and use of thermography in clinical rheumatology practice. The question of whether thermography adds any information that a good history, physical examination and other investigative techniques in current practice do not provide is being addressed. In addition, the role of thermography is being examined by the Professional Affairs Sub-committee of the Australian Rheumatology Association.

Dermatology

The recent availability of short focal length infrared cameras (capable of a resolution of less than 0.1mm) has made possible the use of thermography in dermatological applications(86). Research aimed at differentiating between malignant and non-malignant vascularised lesions is in progress(86). Baillie et al describe the use of the technology to quantify the responses of the skin to various stimuli(104). They concluded IR thermography is a convenient non-invasive technique which would seem to provide a means of discriminating between allergic and irritant reaction of the skin.

Other applications of thermography in dermatology include cellulitis, burns (particularly in relation to the viability of skin grafts and diagnosis of depth of the burn), and vasculitis (Australian Society of Thermology, personal communication).

Other applications

It has been reported that thermography has been used in the design of seating and support surfaces for disabled patients and has been useful in adjustments to limb fitting problems of amputees on thermographic evidence of excess pressure(98). Pressure sores and indolent ulcers may also be monitored by thermography(98). Thermography has also been used in podiatry(105) and in chiropractic rooms(3).

Crisp and coworkers have found thermography useful in localising painful Pagetic lesions in superficial bones(106). In their research they noted that the pain of Paget's disease may be related to bone blood flow and that thermographic monitoring of the lesions provides a quantitative assessment of local disease activity. Studies in the UK dating from 1976 have shown the value of thermography in monitoring treatment, especially intermittent doses (Ring, personal communication). Ring has advised that it is still in regular use with a clinic at the Royal National Hospital for Rheumatic Diseases, Bath for this purpose. The findings support those of Crisp(106) that increased bone blood flow is a prime source of pain and bone pain correlates with the thermographic index which predicts remission or exacerbation.

There have been suggestions the technology could be useful in the early diagnosis of stress fractures in athletes, particularly when used in conjunction with the ultrasound-induced pain test(107).

The Subcommittee of the AAN considered the literature on the application of thermography in spinal cord disease(24). It noted that thermographic abnormalities reportedly occur in more than half of the patients with certain spinal cord abnormalities. Although the case is made that thermography is useful in detection, characterisation, and follow-up, the Subcommittee judged that better approaches are available for this purpose.

Regarding the use of thermography to study the adequacy of blood flow to the hemicranium in order to detect decreased blood flow to the brain, the Subcommittee does not beleive that sufficient evidence has been developed to merit use of the procedure for the clinical assessmnent of transient cerebral ischemia.

Thermography has been used to study patterns of hand and foot use in acts of daily living in patients with acral insensitivity so that activity and footwear can be modified to prevent acral mutilation(24). In a setting where many patients with acral insensitivity are seen, the Subcommittee of the AAN considered that this application seems appropriate.

Institutional reviews of thermography

There have been a number of reviews of thermography by various institutions and organisations.

In 1983, the American Medical Association reviewed the effectiveness of thermography as a diagnostic aid in determining the etiology of low back pain(1). The question was considered by its Diagnostic and Therapeutic Technology Assessment (DATTA) Panel. The panel decided that the procedure was investigational(108). In a follow-up study in 1987 the American Medical Association's Council on Scientific Affairs produced a report on thermography in neurological and musculoskeletal conditions(4).

The report noted that thermography may facilitate the determination of spinal root and distal peripheral nerve dysfunction and also contributes to the evaluation of possible autonomic nervous system dysfunction and of spinal disorders. It may also be useful in documenting peripheral nerve and soft tissue injuries, such as muscle and ligament sprain, inflammation, muscle spasm and myositis. Thermography is helpful in the diagnosis of reflex sympathetic dystrophy and can be used to follow the course of patients after spinal surgery. The report concluded that, in these applications, thermography does not stand alone as a primary diagnostic tool. It is a test of physiological function that may aid in the interpretation of the significance of information obtained by other tests. The report noted the increasing number of correlative studies that had been published but that few of these studies could be characterised as well-controlled. The report concluded that this fact limits attempts at a definitive analysis of the overall value of the technology: more research will help to clarify the exact contribution of thermography to diagnostic problems.

There is some uncertainty regarding the status of the Council's report. The American Medical Association's House of Delegates has not adopted any official policy statement or position on the use of thermography(109). The House of Delegates was dissatisfied with the report, and considered that as it gave thermography undue promotion. The difficulty appeared to be that as the report was submitted as an informational report, it could not be amended or rejected, as is the case with policy reports normally submitted to the House. The House asked the Council on Scientific Affairs to reconsider its report on thermography.

Abernathy has chronicled the American Medical Association's study of thermography(108). She noted suggestions of bias against thermography during the course of the Council's study and that some attempts were made to cast doubts on the standing of the report. Abernathy made the point that the report has the same standing as any other report issued by the Council on Scientific Affairs and approved by the Board of Trustees.

In 1989, the US NCHSR released a technology assessment of thermography (1). In the course of its review of thermography, the US NCHSR obtained opinions on the safety and effectiveness of thermography from the National Institutes of Health (NIH). The NIH advised that there is no compelling evidence to suggest that thermography adds accuracy to the diagnosis of peripheral vascular or cerebrovascular disease or to the diagnosis of spinal root compression. The majority of the papers on the many suggested uses of thermography have deficiencies, such as relatively small numbers of patients and controls, inadequate definition of criteria for establishing presence or absence of thermal gradients, and lack of blinding of interpreters to clinical diagnosis.

Published reports to date do not suggest that thermography is a valuable addition to other diagnostic modalities. The NIH also stated that thermography may only confirm the presence of a temperature difference, that other procedures are needed to reach a specific diagnosis, and thermography may add very little to what the physician already knows based on his history, physical examination, and other laboratory studies. This procedure may prove confirmatory but not diagnostic.

The NIH considered that more experimental research is needed to resolve the existing controversy over the diagnostic efficacy of thermography. The review noted that, while there is no disagreement as to its safety, thermography is considered to be lacking in specificity and inadequate in signal resolution. Others consider it to be somewhat useful as an adjunct diagnostic tool but in need of further definitive testing before efficacy can be unequivocally validated. It was concluded that thermography cannot currently be considered as an essential diagnostic tool since it does not, by itself or as a diagnostic adjunct, add significantly to the accuracy of diagnosing disease.

The view of the US Food and Drug Administration (FDA) is that thermography can only be used as an adjunct to other clinical diagnostic procedures (1). Thermography does not detect nor provide diagnoses of any conditions; rather, it is a method to detect skin surface temperature changes. This information is to be used along with other clinically-accepted methods. Therefore, the FDA believes that thermography should be limited to the role of an adjunctive procedure and should not be used alone as a diagnostic screening procedure.

The US NCHSR report concluded that, the information obtained failed to support claims of efficacy of thermography as a useful diagnostic modality for non-breast indications. Rather, it suggested that thermography lacks sensitivity, specificity, or predictive value. Unassailable data are lacking to indicate that thermography provides a useful guide to monitor the effect of treatment of any disease entity. The evidence suggests that thermography may only confirm the presence of a temperature difference, that other procedures are needed to reach a specific diagnosis, and that thermography may add little to what physicians already know based on history, physical examination, and other studies.

As a result of the above assessment the US Health Care Financing Administration (personal communication) has advised that a notice will be published in the near future in the Federal Register announcing the proposed withdrawal of coverage under Medicare of thermography for the diagnosis of conditions in anatomic areas other than the breast. The proposed notice will provide a comment period during which all interested parties will be invited to express their views. A decision will be made after a thorough review of all information and comments received.

The Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology published a statement in 1990 on the use of thermography in neurologic practice(24). In reviewing the published reports on the value of thermography in this area, the Subcommittee found considerable polarisation of opinion. Some respondents reported excessive and inappropriate use of the technique. The majority thought that the technique was useful for certain specific purposes.

The Subcommittee found that thermography is useful in neurologic practice but that it is better for some purposes than others and that further critical work is needed to define its use, value, and limitations.

The Subcommittee concluded that, based on the present literature:

- IR thermography is of limited value in the characterisation of neurologic dysfunction or deficit. If it is to be used, it should be in conjunction with established neurodiagnostic evaluative procedures. IR thermography may provide information about altered cutaneous temperatures useful in characterising RSD, focal autonomic neuropathies, focal nerve injuries, and for evaluation of faulty use of insensitive acral parts.
- IR thermography has not been shown to provide sufficient reliable characterising information about neurologic dysfunction or deficit to accept it as a proven evaluative procedure for the diagnosis or characterisation of
  - neck or back pain and/or cervical, thoracic, or lumbosacral radiculopathy;
  - musculoskeletal pain;
  - entrapment neuropathy; or
  - headache, transient ischemia, or stroke.

Hubbard recently published an analysis of criticisms of the medical usefulness of thermography prepared by various organisations (110). He examined the significant points and issues raised by these criticisms, including clinical usefulness, abuse/misuse, published reports, and community acceptance of thermography. He also addressed the contradictions in the criticisms of thermography as well as the role of political pressures in its assessment.

Regarding the statements that thermography is an adjunctive test he argues it is difficult to separate an adjunctive test from a primary test and claims that results from thermography are non specific ignore the importance of vasomotor changes in response to neurovasomotor injury. Allegations of misuse/abuse of the technique are inappropriate as other diagnostic procedures are not immune to this problem. He noted that perceived deficiencies concerning lack of prospective, blinded studies had already been answered in previous articles. Similarly the issue of control groups is superfluous as patients serve as their own controls because of thermal symmetry between homologous surface body parts. Hubbard questioned the statement that infers peer acceptance as a criterion of scientific validity. He also pointed out the contradictory statements that are widespread in the technological assessments of thermography. He cited examples from the US NCHSR and the AAN assessments. Hubbard stated that political pressure has had a negative effect upon thermography, this being particularly evident in the assessments by specialty organisations.

Hubbard concluded that more studies need to be published in the mainstream literature of the specialty journals. Much of the supportive literature has been confined to thermography journals. He also stated that influential political factors are seeking to undermine the clinical use of thermography. Finally, he considered that, while some criticisms are offered because of genuine concerns, many are based upon a political agenda and prejudice.

A special committee of the American College of Radiology Commission on Technology Assessment recently prepared a report on the effectiveness of thermography (American College of Radiology, personal communication). The committee considered the reports by the US NCHSR, the AAN, comments from the NIH and the FDA as well as the critique of criticisms by Hubbard and submissions from individuals. The majority of the committee agreed to the following conclusions:

- Thermography is safe. Since the examination requires time for environmental equilibration, the examination may be lengthy, and the information gained from the study measured against the investment of institutional resources and the time expended by the patient may be disproportionately small. The cost/benefit ratio is disadvantageous.

- Clinical application studies have shown no primary diagnostic value for thermography in any extramammary location. Moreover, these studies have documented little added value when compared to other tests and no evidence of improved outcome for patients as a result of employment of thermography.

- While the effectiveness of thermography as a diagnostic test in clinical situations remains controversial, the evidence for its clinical application has not been convincing to the medical community. Thermography is used by few physician practitioners in any field, and the subject is not often taught or even mentioned in medical school or residence training. No recognised medical specialty requires thermography in their accreditation process, and specialty societies, especially those in neurology, neurosurgery, radiology and orthopedic surgery, have not approved thermography as a diagnostic modality.

- Most of the investigations of possible clinical applications suffer from improper research design, relatively small numbers of patients and controls, inadequate definition of criteria for establishing presence or absence of thermal gradients and lack of blinding of interpreters to clinical diagnosis.

- Charging a professional fee for a study which is not accepted by a majority of one's peers may raise questions of ethical propriety.

The majority of the committee agreed to recommend the following to the American College of Radiology:

- Accept the report by the US NCHSR as an accurate and neutral summary of the literature.

- Declare that extramammary thermography has not been demonstrated convincingly to have value as a screening, diagnostic or adjunctive imaging tool.

- Support the withdrawal of Medicare and third party insurance coverage for extramammary thermographic procedures. In an economic environment of finite resources, choices must be made that allocate resources in the best possible manner. Thermography, not having achieved high clinical priority, may not be entitled to broad based financial support.

- Recommend that further research to demonstrate the potential efficacy of extramammary thermography may be appropriate, but only if it is based on promising information from new understanding of fundamental patho-physiology, improved technology or substantial scientific documentation of clinical efficacy.

The member of the committee who disagreed with the conclusions and recommendations stated that thermography is the only imaging modality which documents autonomic nervous system changes associated with pain related to structural abnormalities. Although the structural abnormalities are often clearly depicted by CT and MRI, findings on these modalities do not always coincide with patients' clinical complaints. Concomitant thermography, if positive, serves to enhance the clinical significance of anatomic abnormalities shown by CT and MRI. Conversely, he argued, a normal thermogram may support more conservative or alternate patient management. He noted that thermography, as opposed to other imaging studies, offers data which, being physiologic, are different in nature and scope and are therefore not suitable for blinded studies.

The Commission agreed with the conclusions and recommendations of the report. However the report has not yet been acted upon by the Council which is the policy setting body of the American College of Radiologists (American College of Radiologists, personal communication).

Medico-legal issues

The use of thermography as an indicator of physiological processes related to pain, has made it a controversial medicolegal tool (3). The potential legal implication have been noted by many authors (2,22,25,28,29,111,112,113).

Rein has stated that thermography fits the practice of physicians who concern themselves with the diagnosis and evaluation of injured patients for function loss, impairment and disability (114). Lawyers argue the use of thermography to decide whether certain damages exist, whether there is an important physiologic function loss, whether permanence can be shown, and whether objective evidence of injury exists (114).

Wexler and Chafetz reported on 47 thermograms performed on 32 symptomatic worker's compensation patients. They found normal thermograms in 81 per cent, 100 per cent and 29 per cent of the cervical, thoracic and lumbar regions respectively (111). They commented that, outside the setting of disability claimants, normal thermograms are very rare among patients who have otherwise demonstrable abnormalities compatible with nerve fibre irritation on myelograms and spinal CT scans. Thus, a normal thermogram is an indication that the likelihood of demonstrating an abnormality on a more invasive exam is remote. This suggested to the authors that a large number of the disability claimants studied were describing nerve irritation that was below the threshold of a sensitive technique, and that their pain was psychogenic in origin, or that it is fictitious. They concluded that not only has thermography a place as a screening examination to help identify those patients who should be considered for a more invasive exam, but also may provide a sound basis for the denial of a medical liability claim.

The use of thermography has also been advocated in pre-employment examinations to help identify and document existing injuries or potential problems (112). Applicants may be steered away from potentially hazardous occupations or from strenuous physical activities. Thus if an employee claims a work-related injury, the pre-employment thermogram can be used as a baseline for reference and comparison purposes.

There are current concerns in Australia, particularly among third party payers regarding the necessity for and the clinical usefulness of thermographic examinations. Some court cases involving the use of thermography have already been heard.

Cost considerations

In the US, the Medicare program covers thermography when the procedure is performed by a physician or under his direct supervision; however only a physician can interpret the results. Under this scheme, the use of thermography is indicated when disease is suspected and not as a screening device for ostensibly healthy individuals. The following indications are presently covered:

- peripheral vascular disease (eg thrombophlebitis, arterial insufficiency);
- musculoskeletal injury (eg low back injury involving musculoligamentous soft tissue or herniated disc); and
- cervical thermography for diagnosis of extracranial vessel disease causing CNS symptons (carotid insufficiency), and for diagnosis of inflammatory, neoplastic, and hyperplastic lesions.

In Australia, Medicare benefits are not payable for any thermographic examinations. However information provided by the Australian Society of Thermology suggests that thermography is covered by insurance agencies and rebates to private cases are available on the basis of referred physician consultation (115). In the main thermography appears to be used in the investigation of compensable conditions.

Third party insurers have expressed concern about the costs generated by the use of this technology as the cost of thermograms has varied from $60 to $700 depending on the number of regions scanned (which may be up to 10 scans for a person with a back complaint). The newly formed Australian Society of Thermology has advised it is conscious of the concerns of third party insurers and has recommended a standard fee of $330, irrespective of whether the thermogram is taken of the upper or lower body or the complexity of subsequent analysis. Follow-up examinations would be charged at between $150-$180. Some previous charges for thermographic examinations were based on an equivalent cost of an X-ray for the area viewed (Thomas, personal communication).

A number of authors have suggested that use of thermography may lead to early diagnosis, treatment and preventive measures which would avoid the high cost of manpower loss, medical care(41) and the use of other more invasive, expensive tests(27). Others have noted the absence of cost effectiveness data(8,116). In 1986 Wexler stated that thermography 'offers a relatively economical means for the determination of those patients most likely to benefit by more extensive (and expensive) diagnostic evaluations while simultaneously identifying those who can be readily transferred to conservative medical management with the confident expectation that these individuals will respond positively without further diagnostic evaluations being required. I look forward to the day when such cost-benefit data are available for all parties to consider'(116). More recently in 1989 So et al noted that 'the cost effectiveness of the technique has not been defined'(8).

Goodman reported on his decision and cost effectiveness analyses of thermography and venography in the diagnosis of deep vein thrombosis (117,118). He evaluated a model involving three approaches: empirically treating all patients with anticoagulation without prior testing; ordering venography and treating only those patients with positive tests; and ordering thermography, not treating patients with negative results and perform confirmatory venography in patients with positive thermography results. The results of his decision analysis suggested that a physician caring for a patient with findings suggestive of DVT should opt for either venography or thermography rather than empiric anticoagulation. He noted that the decision between the two modalities is extremely sensitive to the usual range of outcome probabilities and the prevalence of DVT.

The results of Goodman's cost effectiveness analysis supported the performance of thermography first with only those testing positive to undergo venography. He found that the marginal cost benefit could vary from less than $US2000 to more than $US7000 under reasonable ranges of disease prevalence and or the costs of diagnosis, confounding the difficulty faced by societal decision makers in placing a value on the extra cases detected by the venography-alone strategy.

The Australian Society of Thermology (personal communication) has stated that most practitioners in Australia use thermography for the assessment of sympathetic nerve dysfunction and musculoskeletal disorders. The very low false negative rate for this procedure has a potential to save considerable costs to the health insurance industry by avoiding more expensive and invasive techniques such as CT, myelography, and MRI scanning in patients with normal thermal images and who are very unlikely to have significant pathology.

Determining the potential total national cost of thermography is difficult due to the number of applications and the absence of data on the frequency of use in those applications. However an estimate for the use of thermography in low back pain is possible.

Thermography is recommended for patients with low back pain (LBP) where it is felt necessary to proceed beyond conservative therapy work-up (23). Lee has reported an annual incidence of back pain of 2-5 per cent of the population (119), of which only 7-10 per cent of cases will eventually become chronic sufferers (120). This represents in Australia between 336,134 and 840,335 low back pain patients of which between 23,529 and 84,034 will become chronic sufferers. Tait has stated that for most patients with back pain intensive investigations are not necessary, but that more complicated investigations are only necessary in patients with chronic back pain (121).

Assuming that all chronic LBP sufferers have thermography scans on two separate occasions at a cost of $480, the total cost of thermography would be in the range $11.3 to $40.3 million per annum. This estimate excludes consideration of the many other applications of thermography.

As most studies have recommended thermography as an adjunctive test this estimate would be an additional cost to the health care sector.

The potential for thermography therefore to generate large costs to the health care sector are great. There have been suggestions in the literature of off-setting savings through avoidance of other more expensive and more invasive investigations. There appear to be a lack of studies that document and quantify these benefits. Similarly clinical reports describing the effect of thermography on management of the patient are lacking.

Discussion

In the course of this study, a number of views have been expressed by Australian organisations and individuals and reflect the polarised views encountered overseas.

Bogduk (personal communication) has commented that research has established that thermography is particularly sensitive for demonstrating the consequences of nerve injury. When peripheral cutaneous nerves have been damaged by trauma or disease, thermography will demonstrate characteristic differences in superficial body temperature. He argues however, that in this regard, thermography does not reveal any information that cannot be obtained otherwise by a thorough clinical examination which would detect the cutaneous sensory loss associated with the nerve injury.

Bogduk further points out that the value of thermography in musculoskeletal complaints is based on the assumption that patients with joint injuries or muscular problems regularly have characteristic reflex changes in cutaneous blood flow near or in the region affected by the primary musculoskeletal problem. In this regard definitive evidence is currently lacking. He points out that there are no reliable studies that indicate:

- how regularly such reflex changes occur in patients with musculoskeletal injuries;
- how characteristic any particular change is of a particular underlying lesion;
- what the sensitivity of thermography is in such cases, that is how much of a temperature asymmetry must occur before the observation is diagnostic.

Mastroianni (personal communication) has expressed his concerns regarding the use of thermography in soft tissue injuries and in reflex sympathetic dystrophy. He notes that individuals with painful upper limbs caused by repetitive work often seem to be referred for the test. He suggests that controlled studies are required to compare thermograms of asymptomatic people working in occupations involving repetitive work such as process workers and keyboard operators with those not involved in the same industries and then compare those findings with symptomatic people working in the same industries. Such studies could provide a baseline of information which then could be used to evaluate the technology. He also expressed his concerns regarding the morbidity of subsequent treatment given on the diagnosis made by thermographic assessment.

Awerbuch (personal communication) considers that thermography appears to have no particular application which is unequivocally superior to conventional diagnostic imaging modalities. He notes poor design of the majority of clinical studies which have attempted to evaluate the diagnostic efficacy of thermography. Because of a high incidence of false negative results in certain situations in which it is used, thermography may be considered potentially dangerous, leading to delays in diagnosis. He further states that the ease with which a thermographic clinic may be established and the absence of necessary certification of the operator will inevitably mean that the usual checks and balances on the standards and veracity of reports which operate in conventional radiological units will be bypassed. In his opinion, detailed analysis of the available data argue against the diagnostic efficacy of thermography in almost every role for which it is proposed.

Cherry (personal communication) comments that the proposed uses of neuromuscular thermography are vague and unsubstantiated and adequate clinical trials are required to show the technique's efficacy.

Similarly concerns have been expressed regarding the instructions given to patients prior to examination. The need for avoidance of certain situations and actions prior to the test, in one instance days prior to the test, would appear to make the thermogram extremely sensitive to interfering factors. Therefore the value of a thermogram when it is so easily influenced by these physical conditions, is being questioned.

Concerns have also been expressed regarding the training and supervision of the operator (other than the medical practitioner) performing the scan. This may be particularly important if thermographic examinations are performed in non-physician rooms, such as in chiropractic offices.

The Royal Australasian College of Physicians (personal communication) has noted that changes detected by thermography are secondary and these changes correlate well with the patient's clinical condition. However the College considers that the technique must still be regarded as experimental as there are no good studies evaluating this technique for routine clinical practice. Furthermore, changes in thermography could not be equated with proof of whether the patient has pain, dysfunction or musculoskeletal disease.

The Australasian College of Physical Scientists and Engineers in Medicine (personal communication) also has questioned the diagnostic usefulness of the technology.

A number of comments have been received in support of thermography.

The Australian Society of Thermology (personal communication) stresses that the international use of thermography by many clinicians over the last 20 years has demonstrated the usefulness of this technique in a number of conditions including reflex sympathetic dystrophy, various rheumatological, orthopedic, dermatological and neurological conditions, certain vascular disorders, and in breast cancer. The Society further comments that the information provided by thermography is complementary to other diagnostic techniques such as CT, EMG, myelography, bone scan and conventional radiology and is in no way antagonistic since it provides a different type of clinical information which is physiological and not anatomical. The technique is of particular use in patients where diagnosis is still awaited despite conventional investigation.

The Society has submitted that controversial aspects of thermography are nonexistent in many parts of the world and it is only in the US and Australia where the technique is used in a medico-legal context that the controversial aspects have been promoted. The Society points out the formation of overseas thermography societies and that thermography has been practised in England and Japan since the early 1960s, and in Japan thermography is accepted by the medical profession at large. It also suggests that the reluctance of doctors to use the technique is largely due to lack of awareness of what the technique is intending to show and also a lack of awareness of the over 5,000 scientific articles that have been published showing the technique to have validity.

The Royal Australasian College of Radiologists has stated that the various uses of thermography which the Australian Society of Thermology recommends encompasses the views of the College.

Leonello (personal communication) has stated that he has found the technique of particular value in RSD and is capable of picking up this disorder early before trophic tissue changes occur. He also has found it useful in chronic myofascial pain problems and in lumbar and cervical radiculopathy. In his opinion the value of thermography is that it provides information which is complementary to other clinical information and which often helps to complete the clinical picture.

The literature and opinions on thermography therefore present strong and polarised views on the usefulness of the technology.

Thermography is a safe noninvasive imaging modality which relies upon the detection and measurement of IR radiation from the body surface for diagnostic purposes. The IR radiation is related to skin temperature which is a reflection of cutaneous blood flow under the control of the autonomic nervous system.

It is generally assumed that IR thermography is an accurate method of measuring cutaneous temperature. However the actual value of the temperature measurements, particularly on curved surfaces of the body has been questioned. Errors greater than the temperatures changes caused by underlying pathology are possible. Potential technical limitations have also been pointed out.

Studies have shown that there are temperature differences among anatomic sites but only small temperature differences between corresponding areas on opposite sides of the body. This side-to-side thermal symmetry is thought to represent normal physiological function. Normal values for the different areas of the body have been published and are being used in the interpretation of thermograms. However some literature has suggested that the variabilities related to the influence of site, age, sex, height, weight, physiologic condition and disease variables have not been explored adequately. Further work has also been suggested to better define the underlying pathophysiologic mechanisms associated with IR energy emission changes following nerve injury and venous occlusion.

High sensitivities have been reported in many studies for thermography in the diagnosis of neuromuscular disorders such as entrapment neuropathies and cervical and lumbar radiculopathies. However the adequacy of some of the studies has been challenged, particularly in relation to methodology. Some recent studies do not support these good results.

It has been suggested that the medical profession is sceptical of the procedure because there does not appear to be a controlled, double-blind study by a major teaching institution verifying the accuracy of thermography (112).

Overseas institutional reviews and US government agencies agree that further research is required to determine the efficacy of the technology. Data are also lacking concerning the cost effectiveness and the effect of patient management with the use of the technology.

Quantification of the cost of the technology to the health care sector has proved difficult. The estimates of between $11.3 and $40.3 million per annum for application of thermography to chronic low back pain patients is an indicator of the potential cost of the technology were it to be more widely applied. The total cost of thermography would be very much higher if the technology was used in the range of applications. The literature has inferred savings from avoidance of more expensive investigations and savings in hospital stays. However there is an absence of data substantiating these savings.

The question that needs to be addressed is whether thermography adds any information that patient history, physical examination and other investigations in current practice do not provide in the clinical decision making process. Goldie, reflecting on his experience with thermography over 15 years, considered that in orthopedics, the test confirms clinical impression and physical examination (122). The test adds to the number of diagnostic aids and the pictorial registration of emitted temperatue variations in biologic tissues, does not yield information which improves on already existing methods (122).

There appears to be an absence of clinical studies that have measured patient health outcome in terms of use of thermography. The literature reveals that most researchers advocate the use of thermography as a screening tool or as showing potential or promise in particular applications.

Although thermography is widely applied, its use remains controversial. The apparent lack of information on the impact on patient management and cost effectiveness of thermography has contributed to this debate. Further, criticisms of studies establishing its validity have made the value of thermography uncertain. Wide support for this technology would be difficult to justify without relevant data in these areas.

It is recommended that appropriate well designed clinical trials be established to determine the cost effectiveness and impact of thermography on patient management.

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