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Infrared Thermography in the Detection and Management of Coronary Artery Disease

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Infrared thermography was used to measure and map precordial skin temperature in 60 patients undergoing elective coronary angiography; 9 patients were normal and 51 had coronary artery disease (CAD). Thermograms were graded by quartile area (zero to 4 plus) and magnitude of thermal asymmetry (recorded as degrees celsius). The presence, mean area and degree of thermal asymmetry were significantly greater in patients with CAD. Twenty-two patients subsequently underwent successful revascularization with angioplasty with a highly significant decrease in the presence, magnitude and degree of thermal asymmetry. The results demonstrate that CAD is associated with precordial thermal asymmetry. The area and magnitude of thermal asymmetry is greater in patients with CAD than in control subjects without angiographically significant CAD. Successful revascularization changed the asymmetric precordial pattern to a more symmetric one. Infrared thermography is a promising technique for the detection of CAD before and after revascularization.

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Infrared thermography is a noninvasive technique that allows the body's skin temperature to be mapped. Precordial skin temperature is largely controlled by the autonomic nervous system, regulating vasomotor tone, and is both anatomically and physiologically symmetric. Prior work with infrared thermography has established that there is normally thermal symmetry.¹ Cold exposure can cause diffuse temperature changes without altering normal symmetry between homologous regions. Asymmetric changes in precordial skin temperature may result from changes in local vasomotor tone due to autonomic activation (and angina through viscerosomatic convergence). In patients with angina pectoris, thermal asymmetry has been variably reported to occur at rest in the absence of chest pain, and with exertional chest pain.^{2,3}

METHODS

The Agema Thermovision 870 electronically cooled infrared system was used for thermographic imaging with color stills recorded for subsequent analysis and documentation of results. The most frequently used scale was in 0.5°C increments.

Infrared thermograms were performed in 60 patients undergoing elective cardiac catheterization after informed consent had been obtained. Infrared thermograms were repeated after revascularization in patients undergoing percutaneous coronary angioplasty. The infrared thermograms were interpreted by a physician without knowledge of the patient's clinical status or coronary anatomy.

In interpreting the infrared thermograms the right and left precordium were each divided into quadrants to yield a semiquantitative measure of the area of thermal asymmetry (0 to 4 quadrants). The magnitude of thermal asymmetry was measured in 0.5°C increments, with rounding of each area occurring to the nearest 0.5°C.

The coronary angiograms were reviewed by 2 independent angiographers. Significant coronary artery disease (CAD) was diagnosed if >50% narrowing was noted in any epicardial artery. A patient without any epicardial stenoses >50% was categorized as being without significant CAD (normal). If the patient had a prior complete revascularization so that no unprotected areas were noted on angiography, he was also classified as being without significant CAD (normal).

The differences in precordial symmetry between normal patients and patients with CAD were evaluated using chi-square analysis. An unpaired 2-tailed Student's *t* test was used to compare the magnitude and extent of thermal differences in normal subjects versus patients with CAD. Precordial thermal symmetry was compared

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in patients before and after angioplasty using a chi-square test. A paired 2-tailed Student's *t* test was used to compare the magnitude and extent of thermal differences in normal patients before and after angioplasty. All results are given as mean \pm SEM.

Patients with diagnoses of noncoronary heart disease, primary pulmonary hypertension, and breast pathology (neoplasm, inflammation) were excluded from the study.

This investigative protocol was approved by the institutional review board for human subjects.

RESULTS

Infrared thermograms were obtained in 60 patients (46 men and 14 women) aged 32 to 80 years. There were 9 patients without significant CAD (normal) and 51 patients with CAD. Twenty-three of the patients with CAD underwent angioplasty, successfully in 22 of the 23.

In the 9 patients without significant CAD, 6 had normal precordial thermal symmetry (Figure 1); 3 were asymmetric. By contrast, of the 51 patients with CAD only 3 had precordial thermal symmetry; the other 48 had thermal asymmetry (Figure 2). All 23 patients undergoing attempted angioplasty had asymmetric thermograms at baseline. After successful angioplasty, 18 of the 22 patients had symmetric thermograms. In the remaining 4 patients (3 complete, 1 incomplete revascularization), the infrared thermogram remained unchanged in 2 and showed improvement in 2. The patient with an unsuccessful attempt at angioplasty showed an unchanged postprocedure thermogram.

There were 19 patients with 1-vessel CAD, a number too small to demonstrate any statistically significant pattern of thermal asymmetry characterizing a specific epicardial coronary artery. The small number of women and normal men does not permit any inference as to whether a differential in sensitivity or specificity of thermography for CAD detection exists between the sexes.

There was a highly significant difference between the patients without and with CAD in precordial thermal symmetry ($p < 0.005$). Detection of thermal asymmetry showed a 94% sensitivity for the presence of significant CAD. The specificity of an asymmetric thermogram for CAD was 67%. Additionally, significant differences were noted in the area of the thermal asymmetry (1.84 ± 0.14 in patients with CAD vs 0.56 ± 0.29 in normal subjects, $p < 0.001$) and the magnitude of the temperature differential ($0.91 \pm 0.05^\circ\text{C}$ in those with CAD vs $0.33 \pm 0.19^\circ\text{C}$ in normal subjects, $p < 0.001$).

In patients who had undergone successful angioplasty there was a highly significant difference in thermal symmetry before and after revascularization ($p < 0.005$). There were again highly significant differences in the area (1.77 ± 0.21 before vs 0.18 ± 0.08 after revascularization, $p < 0.001$) and magnitude ($0.98 \pm 0.07^\circ\text{C}$ before vs $0.11 \pm 0.06^\circ\text{C}$ after revascularization, $p < 0.001$) of asymmetry between the groups before and after angioplasty.

DISCUSSION

Malliani et al⁴ and Foreman and Ohata⁵ studied the effects of transient coronary artery occlusion in cats on

the afferent cardiac sympathetic fibers, demonstrating their involvement in both transmission of impulses perceived as cardiac pain and in spinal sympathetic reflexes. Efferent sympathetic nerve activity has been shown by Normell and Wallin⁶ to regulate the cutaneous thermoregulatory vasomotor response and skin temperature in humans. The skin temperature changes evoked by sympathetic stimuli were slow (maximal effect after 30 seconds) and prolonged (several minutes in duration).

Conflicting results have been reported on the presence and incidence of precordial skin temperature asymmetry at rest in patients with clinical angina pectoris. Doret and Ferrero³ found thermographic asymmetry in 15 of 21 patients in between episodes of angina pectoris. Conversely, Potanin and associates² found 41 of the 50 patients with angina pectoris to have thermal symmetry at rest. Thermal abnormalities developed in 17 of 22 patients with chest pain during exercise, and was related temporally and to the location of the chest pain. The remaining 28 patients without exertional chest pain also did not develop thermal abnormalities.

In the present study, infrared thermography appears to be a highly sensitive and reasonably specific technique for the detection of CAD. Particularly noteworthy

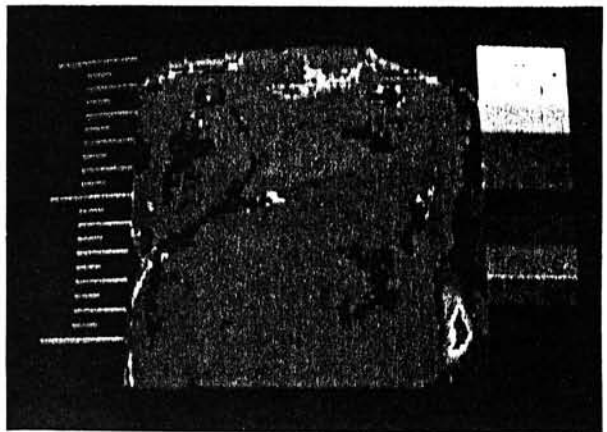


FIGURE 1. Infrared thermogram of a normal patient's chest showing a homogeneous temperature distribution.

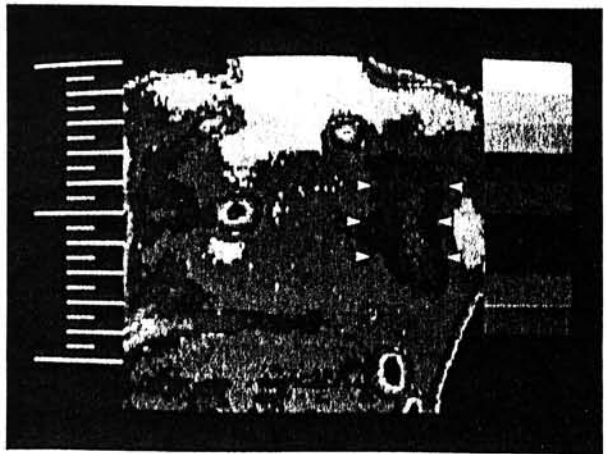


FIGURE 2. Infrared thermogram of the chest of a patient with coronary disease showing thermal asymmetry and inhomogeneity.

is the conversion of asymmetric to symmetric thermograms after successful angioplasty. Infrared thermography may have a role in monitoring for acute closure and restenosis after angioplasty. In contrast to previous studies using clinical angina, this study used angiographic criteria for coronary disease. The present group may have had more severe CAD or may have been more unstable (i.e., catheterization referral may imply failure of medical therapy) than previously studied groups.

The subjects in the present study (patients referred for cardiac catheterization) are obviously a group with a high prevalence of CAD. Even those patients with "normal" epicardial vessels may have had vasospastic angina or small vessel disease. Indeed, 2 of the 3 false-positive results (for thermal asymmetry) were in patients with reversible thallium perfusion defects. A different sensitivity and specificity would be likely to prevail in a group of patients with a different prevalence of CAD.

The precordial asymmetry in patients with CAD occurred in the absence of angina. This might imply either persistent autonomic activation in patients with significant CAD or alternatively ongoing ischemia at a sub-

perceptual level. Whether patients with CAD and silent ischemia or those with autonomic neuropathy are capable of similarly manifesting thermal precordial asymmetry was not addressed in the present study. Infrared thermography may prove to be a useful tool in investigating the link between coronary ischemia, nervous system activation and perception. The present study did not attempt to address whether thermal asymmetry was a graded response effected by the duration, severity or recovery time from coronary ischemia.

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