Detecting Carotid Occlusive Disease by Thermography

BY T. D. CAPISTRANT, M.D., AND R. J. GUMNIT, M.D.

Abstract: Detecting Carotid Occlusive Disease by Thermography

The ability of facial thermography to detect disease in the internal carotid artery was evaluated. Unilateral forehead cooling of 0.7°C or greater was observed in 57% of 30 cases with angiographically proved stenosis. Two provocative tests, facial cooling and a head clamp, increased the sensitivity rate to 83%. The greatest overall sensitivity and specificity was obtained by using a head clamp especially designed to bilaterally occlude superficial temporal arteries. Facial thermography is a useful screening device in detecting carotid occlusive disease. However, the necessity to use a provocative test to increase the sensitivity to acceptable levels will probably limit its use to the screening of high-risk asymptomatic patients. It does not appear to be economically feasible in the mass screening of healthy individuals.

Introduction

No way has yet been found to reverse the damage to the brain caused by a stroke. If we are to reduce the severe morbidity and mortality of cerebrovascular disease, a way must be found to detect those patients who are prone to have a stroke before the event. In this paper, we evaluate the possible role of infrared thermography as a screening test to detect carotid occlusive disease and as a technique to study the natural history of such lesions.

A complete description of the technique of medical thermography can be found in a paper by Barnes.1 Briefly, a thermogram presents a quantitative display in two dimensions of the heat emitted by the body as infrared energy. These heat emissions are generated primarily by the cutaneous blood supply and thus reflect blood flow in these vessels. The cutaneous vessels of the medial forehead, medial canthus and supraorbital ridge are branches of the internal carotid artery (fig. 1). Under normal circumstances, there is a remarkable symmetry in the heat patterns from these regions. However, when the lumen of the internal carotid artery is significantly compromised, blood flow through these terminal branches is reduced and cooling of the forehead on the side of the lesion can be detected (fig. 2).

Earlier studies of thermography in the detection of carotid narrowing were not completely satisfactory because of problems involving selection factors in the patient populations, lack of objective criteria for determination of an abnormal thermogram and incomplete carotid angiography.2-4 Furthermore, it is necessary to demonstrate the value of thermography in screening a high-risk asymptomatic population as well as to detect lesions in patients who are already symptomatic.

This study was designed to test sensitivity and specificity rates, two major factors in evaluating a screening test, in a group of patients who had received careful neurological evaluation and bilateral carotid angiography.

Methods

Candidates for the study consisted of any patient undergoing cerebral angiography at St. Paul-Ramsey Hospital, St. Paul, Minnesota, and other University of Minnesota affiliated hospitals, without regard to clinical diagnosis. Those with major abnormalities in the forehead integument (e.g., recent trauma or dermatitis) were rejected. There were 201 controls, consisting largely of medical students and nurses under the age of 30 years without neurological disease. All subjects remained in a 70°F room (plus or minus 2°) for 15 minutes prior to the examination. During this period, the technician completed a computerized data sheet which contained room temperature and humidity readings, the patient's temperature, other identifying data, and the clinical indication for angiography. The
The thermogram on the left was obtained from a cadaver following injection of hot water into a catheter sutured into the internal carotid artery in its cervical portion. The white streaks over the face denote the facial branches of the internal carotid artery. In the schematic figure on the right, the major branches are labeled.

The subject was seated or placed in a sitting position in bed with a constant temperature background. The subject's face and an overhead temperature reference scale were scanned simultaneously with a Thermovision infrared

**FIGURE 2A**

Normal thermogram with symmetric heat patterns over the forehead.

**FIGURE 2B**

Abnormal thermogram with dark area over left forehead corresponding to cooling ipsilateral to carotid occlusion.
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camera with an accuracy of ± 0.1°C. Photographs of the oscilloscope image were taken with negative-positive Polaroid film.

Two provocative techniques were used in all patients and one of every ten controls. The first provocative test consisted of a five-minute application of a specially designed head clamp which simultaneously occluded the superficial temporal arteries bilaterally, thereby stress testing the internal carotid supply to these forehead skin vessels (fig. 3). This technique was the subject of an earlier report. The prototype head clamp had a rigid aluminum frame, adjustable straps and two screw-controlled rubber pressure pads. A later model is similar, but the pressure pads are simultaneously adjustable by a pneumatic system with a pressure gauge monitor (fig. 4). The technician positioned the pads over the proximal trunks of the superficial temporal arteries just anterior to the auricle and applied enough pressure to obliterate the distally palpated superficial temporal artery pulsations. In the second provocative test, thermal asymmetries were noted during a 20-minute rewarming period following rapid forehead cooling. Rapid cooling consisted of a 30-second application of a soft rubber bag filled with crushed ice to the forehead.

Thermograms were defined as abnormal when temperature asymmetries in the supraorbital region were 0.7°C or greater. Temperature asymmetries were determined after study of the photographic negative using a Barnes photocomparator transmission densitometer. Light transmissions through the "grayness" of the ten known temperatures of the reference scale were compared to the "gray" regions of the forehead. Photocomparator readings were routinely recorded in all patients and controls in the supraorbital and medial forehead areas (supplied by branches of the internal carotid artery) and in the lateral forehead regions (supplied by external carotid vessels). Determination of abnormality of the thermograms by the visual or

FIGURE 3

Composite diagram showing effects of obliterating collateral circulation to forehead skin arteries bringing out, in the illustrated case, left forehead cooling ipsilateral to internal carotid artery obstruction.

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“eyeball” method was compared to the photocomparator. The ultimate criteria for abnormality, however, rested with the asymmetries in the photocomparator readings.

Stenotic regions detected by carotid angiography were measured with a millimeter rule and compared to the most nearly normal adjacent lumen of the same artery. The degree of stenosis was expressed as the maximum percentage narrowing of the vessel lumen on any x-ray projection. “Significant stenosis” was defined as 50% or greater narrowing. Angiographical and thermographical data were determined in a double-blind manner. The appearance of warmth in the region of the nose as an additional indicator of abnormality of facial thermograms was evaluated.

Results
1. ANGIOGRAPHY
Two hundred seven patients were studied. In 26 instances, the angiograms were not satisfactory for visualization of neck vessels, and in 86 patients only unilateral carotid angiography was performed. Ninety-five patients studied by bilateral carotid or four-vessel selective cerebral angiograms formed the experimental group.

In 30 of the 95 patients significant stenosis or occlusion was found in the cervical portion of the carotid artery. Sixteen patients had occlusion and 14 patients had stenosis of 50% to 99%. All the stenotic lesions and 13 of the occlusions were in the internal carotid artery. The three remaining occlusions were in the common carotid artery. The lesions were arteriosclerotic in origin except for two of the common carotid occlusions which were surgical ligations for intracranial aneurysm. One case numbered among the occlusions had a significant degree of internal carotid artery stenosis on the other side. Bilateral carotid stenosis of greater than 50% occurred in three patients. The average narrowing among the stenotic lesions was 80%. Twenty-three of the 30 patients with carotid occlusive disease demonstrated by angiography were clinically suspected of having some type of cerebrovascular disease prior to angiography. In seven cases, the angiogram was performed for another reason and unsuspected carotid occlusive disease was found.

2. ROUTINE THERMOGRAPHY
Only two of the 201 controls studied by the routine thermographical method were positive (false-positive rate = 1%). Both of the positive cases were completely asymptomatic and had normal neurological examinations. In the total patient population, routine facial thermography was abnormal in 17 of the 30 cases (57%) with carotid occlusive disease. Fourteen of the 30 cases had stenosis; five of these (36%) had abnormal thermograms. Among the 16 cases with occlusion, abnormal thermograms were seen in 12, or 75%, of the cases. Five abnormal thermograms (“questionably false positives”) occurred among the 65 patients without significant cervical carotid stenosis. These cases are analyzed in table 1. One of the abnormal thermograms occurred in a patient with a suspected frontal meningioma where the warmer side of the forehead was ipsilateral to a region of unilateral hyperostosis. Another false-positive thermogram occurred transiently with the ipsilateral cooling occurring on the side of the carotid ophthalmic artery complex involved in a microembolic transient ischemic attack. Two additional patients with false-positive thermograms had scattered cerebrovascular occlusive disease.

Among the three patients with bilateral carotid stenosis, two were positive with routine thermography. In the patient in whom significant stenosis occurred opposite an occluded vessel, the thermogram was positive on the occluded side. One patient with unilateral significant carotid stenosis showed contralateral forehead cooling. On the cooler side, a 20% stenosis occurred in the region of the carotid siphon causing attenuation of the angiographical dye column in the immediate vicinity of the ophthalmic artery origin.

3. THERMOGRAPHY WITH THE HEAD CLAMP PROVOCATIVE TEST
No false positives occurred among the 20 controls studied with the head clamp provocative test. Among the 30 cases with significantly narrowed or occluded carotid arteries, 25 of the 30, or 83%, showed positive thermograms with the head clamp technique. Ten of the 14 cases with stenosis, or 71%, and 15 of 16, or 94%, of the patients with occlusion had positive thermograms. Abnormal thermograms were found in five of the 59 cases with bilateral angiography without significant carotid stenosis or occlusion. These five false positives
<table>
<thead>
<tr>
<th>Case no.</th>
<th>Age</th>
<th>Sex</th>
<th>Admission diagnosis</th>
<th>Routine Thermograms*</th>
<th>Type of angigram</th>
<th>Significant angigram findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>131†</td>
<td>61</td>
<td>M</td>
<td>Carotid-TIA</td>
<td>+ R 1.3</td>
<td>Four-vessel cath.</td>
<td>Right carotid, microembolic episodes, no stenosis</td>
</tr>
<tr>
<td>143</td>
<td>63</td>
<td>F</td>
<td>CVA</td>
<td>− R 0.5</td>
<td>Four-vessel cath.</td>
<td>Branch occlusion of right middle cerebral artery</td>
</tr>
<tr>
<td>202</td>
<td>28</td>
<td>F</td>
<td>Tumor</td>
<td>+ L 1.1</td>
<td>Four-vessel cath.</td>
<td>Normal angiogram; right frontal hyperostosis noted, brain tumor still suspect</td>
</tr>
<tr>
<td>214</td>
<td>49</td>
<td>F</td>
<td>(Headaches) AV malformation</td>
<td>− R 0.5</td>
<td>Four-vessel cath.</td>
<td>Fibromuscular hyperplasia, right carotid-bellied appearance; no significant stenosis or obstruction to blood flow</td>
</tr>
<tr>
<td>221</td>
<td>59</td>
<td>F</td>
<td>Subarachnoid hemorrhage</td>
<td>+ R 1.7</td>
<td>Percutaneous bilateral carotid</td>
<td>Aneurysm, right middle cerebral artery</td>
</tr>
<tr>
<td>222</td>
<td>60</td>
<td>F</td>
<td>CVA-thrombosis</td>
<td>− R 0.3</td>
<td>Four-vessel cath.</td>
<td>Normal</td>
</tr>
<tr>
<td>336</td>
<td>60</td>
<td>M</td>
<td>CVA-occlusion</td>
<td>+ L 1.2</td>
<td>Four-vessel cath.</td>
<td>Occlusion, left vertebral and left subclavian arteries</td>
</tr>
<tr>
<td>414</td>
<td>57</td>
<td>F</td>
<td>Carotid-TIA</td>
<td>+ L 0.8</td>
<td>Percutaneous bilateral carotid</td>
<td>Left internal carotid stenosis, 15%; right internal carotid stenosis, 38%; left external carotid stenosis, 20%; right external carotid stenosis, 10%</td>
</tr>
</tbody>
</table>

*Numbers refer to the differences in temperature; (+) indicates the side was cooler; (−) indicates the side was warmer than the opposite. (R) and (L) indicate right and left.
†This case is the subject of reference #7.
included two of the cases showing false positivity with routine thermography and three additional cases (table 1). The two false-positive thermograms common to both the routine and head clamp methods included the temporary false-positive thermogram noted in the patient with a carotid microembolic attack and the patient with ipsilateral hyperostosis and suspected meningioma. Among the additional false positives was a patient with nonobstructive carotid artery fibromuscular hyperplasia. Two of the three cases with bilateral carotid stenosis were positive with the head clamp technique. The false-negative case was positive with standard thermography.

4. COMBINED ROUTINE AND HEAD CLAMP PROVOCATIVE TEST

When results of routine and head clamp thermograms were combined, overall sensitivity was raised to 90%, stenotic lesions to 79% and occlusions to 100% (table 2). This increase in sensitivity was accompanied by a 4% reduction in overall specificity.

5. THERMOGRAPHY WITH FOREHEAD COOLING PROVOCATIVE TEST

Four of the 20 controls studied with the forehead cooling provocative test had positive thermograms. All four of these cases had normal routine and head clamp thermograms. Among the 30 cases with carotid occlusive disease, 21 of 36 cases, or 81%, had positive thermograms. Sensitivity ranged from eight of 12, or 67%, among the stenoses to 13 of 14, or 93%, among the occlusions. Ten of the 61 cases with normal angiograms showed false-positive thermograms. This 16% false-positive rate among the patient population was double the 8% found among the routine and head clamp series. The results with the cooling provocative test among patients with bilateral carotid disease was the same as that found with the head clamp technique.

6. MISCELLANEOUS RESULTS

Sensitivity and specificity rates calculated by using a $\Delta t$ of 0.6°C and 0.8°C as well as 0.7°C are shown in table 3. The infrared scanning camera detects temperatures with a $\Delta t$ of 0.1°C and these data then show the range of error involved in the final results. One will note from the data that there was no change in sensitivity results from the provocative tests for a varying $\Delta t$ between 0.6°C and 0.8°C. There was, however, a wide variation in the sensitivity rates for routine thermography showing that the temperature asymmetries were larger; therefore, abnormal results were more easily determined among the provocative test thermograms.

Wallace suggested that the appearance of a relatively warm nose on a facial thermogram was a
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TABLE 4
Thermograms Showing Warmer Nose Tips for Patients With Internal Carotid Stenosis or Occlusion, Patients With Less Than 50% or No Stenosis, and Controls

<table>
<thead>
<tr>
<th></th>
<th>Positive anglogram  (&gt; 50% stenosis)</th>
<th>Negative anglogram  (&lt; 50% stenosis)</th>
<th>Controls (no anglogram)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warmer nose tip</td>
<td>15/30 50%</td>
<td>23/65 35%</td>
<td>44/201 22%</td>
</tr>
<tr>
<td>Uniform nose</td>
<td>11/30 37%</td>
<td>40/65 62%</td>
<td>127/201 63%</td>
</tr>
<tr>
<td>Unknown</td>
<td>4/30 13%</td>
<td>2/65 7%</td>
<td>30/201 15%</td>
</tr>
</tbody>
</table>

*This group consists of thermograms in which the entire nose was not included in the thermogram Polaroid print.

useful indicator of abnormality. Table 4 shows data using a warm nose as the only criterion of abnormality in the patient and control populations. Although there is a tendency for a warm nose to occur more frequently among patients with abnormal angiograms (50%) than among those with normal angiograms (35%) and controls (22%), this was not a particularly reliable finding.

7. SUMMARY OF RESULTS
Overall sensitivity of thermography in detecting carotid occlusive disease was 57% by the routine method, 83% by the head clamp and 81% by the cool techniques. Specificity rates were 92% for the routine and head clamp techniques and 84% for the cooled method. Routine thermography predicted only 36% of the stenoses and 75% of the occlusions. The head clamp provocative test increased these rates to 71% and 94%, respectively. Although similar increases in sensitivity were found with the cooling provocative test, an excessive number of false positives occurred among the controls (20%) and in the patient population (16%). Combined head clamp and routine thermography yielded an overall sensitivity of 90% and specificity of 88% (table 2).

Discussion
Best overall sensitivity and specificity were obtained with the use of the head clamp provocative test. The cooling provocative test, while providing an increase in sensitivity, resulted in a decreased specificity (an increase in the number of false positives), both among the controls and in the patient population.

The facial temperature asymmetries noted among the abnormal thermograms occurred in four basic patterns. A composite sketch illustrating the configuration of these cool regions is shown in figure 5.* Awareness of the variety of patterns and combinations of patterns in facial cooling was important in raising sensitivity.

*Figure 5 reprinted with permission from the Journal of Radiology.

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Photocomparator readings were helpful in determining precise temperature asymmetries across the forehead. However, the visual scanning or eyeball method of determining temperature asymmetries compared quite favorably. The "warm nose" sign proposed by Wallace did not prove to be a reliable indicator of thermographical abnormality among patients with abnormal angiograms and occurred in a high percentage of controls and

FIGURE 5
Schematic composite sketch depicting the four basic patterns of thermal asymmetry recognized in patients with carotid occlusive disease.
patients with no significant angiographical evidence of carotid disease. Thermography was less sensitive in depicting patients with carotid stenosis than with carotid occlusion, and less sensitive in patients with asymptomatic as opposed to symptomatic cerebrovascular disease. These findings, in addition to the need to use a provocative test (superficial temporal artery head clamp) to reach acceptable levels of sensitivity, limit the usefulness of thermography as a screening test. It cannot be relied upon in a clinical cerebrovascular suspect to rule out the necessity for angiography in determining carotid occlusive disease. It can serve in the same manner as other previously described tests (e.g., ophthalmodynamometry, EEG changes with carotid compression) to select candidates for further study from a group of patients with borderline indications for cerebral angiography.

Thermography may have its greatest use in detecting carotid occlusive disease among a group of high-risk, asymptomatic patients. Such patients include those with hypertension, diabetes and hyperlipidemia. Yearly study of such a patient population would give important data on the natural history of carotid occlusive disease and, in certain instances, would be helpful to the patient's physician who may better interpret any of the early symptoms of cerebrovascular insufficiency.

**Conclusion**
Facial thermography is a useful screening tool for carotid occlusive disease if used with a provocative test (in our series the superficial temporal artery head clamp). The greatest usefulness of this technique may lie in periodic screening of a high-risk, asymptomatic population.

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