The Value of Noninvasive Investigation in the Diagnosis of Total Occlusion of the Internal Carotid Artery

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SUMMARY A battery of simple noninvasive tests consisting of directional Doppler ultrasound and carotid phonoangiography has been used to detect carotid stenosis in 700 patients. Forty four carotid occlusions in 42 patients were confirmed on angiography, and this study examines the accuracy of this noninvasive battery in predicting the presence of an occluded internal carotid artery. Although the sensitivity of the battery described has been 70% for occlusion, with a specificity of 98% (only five false positives), this relatively low sensitivity and the uniform requirement for surgery in the false positive group have led us to conclude that this battery should not be used as a substitute for angiography when the diagnosis of internal carotid occlusion requires to be confirmed. Nevertheless, these noninvasive tests do have a role in alerting the physician to the presence of carotid occlusion and contralateral carotid artery stenosis, allowing more specific planning of any subsequent arteriography required.

NONINVASIVE INVESTIGATIONS of various types have gained widespread acceptance in the diagnosis of haemodynamically significant stenosis of the internal carotid artery. Such noninvasive investigations include supra-orbital Doppler ultrasound testing, carotid phonoangiography, supraorbital photoplethysmography, fluid and air filled ocular plethysmography, duplex B-mode and Doppler imaging and velocity waveform and spectral analysis. These increasingly sophisticated and expensive modalities of investigation have been associated with, in most instances, a progressive increase in sensitivity in the diagnosis of carotid arterial stenotic disease. In particular, combination of noninvasive tests has resulted in sensitivities as high as 95%. Few of these investigations, however, have been documented to have an acceptable accuracy in the diagnosis of total occlusion of the internal carotid artery. Three studies have achieved better than 85% sensitivity for the noninvasive diagnosis of carotid occlusion, one using duplex pulsed Doppler and real time B-mode ultrasonography, and two studies using spectral analysis.

In the Vascular Laboratory of the Johannesburg Hospital we routinely use a battery of simple, inexpensive noninvasive tests in the Vascular Laboratory of the Johannesburg Hospital. This group of patients was drawn from both the Cerebrovascular Clinic as well as referrals from the general medical and surgical population of the Johannesburg Hospital. The battery of tests consists of carotid phonoangiography, supraorbital Doppler evaluation and continuous wave directional Doppler evaluation of the common, internal and external carotid arteries. The majority of patients included in this study were referred to the Vascular Laboratory because of a history of transient ischaemic events or minor stroke with good recovery, but some patients with an asymptomatic carotid bruit were included.

Patients and Methods

Seven hundred patients have been evaluated by a battery of noninvasive tests in the Vascular Laboratory of the Johannesburg Hospital. This group of patients was drawn from both the Cerebrovascular Clinic as well as referrals from the general medical and surgical population of the Johannesburg Hospital. The battery of tests consists of carotid phonoangiography, supraorbital Doppler evaluation and continuous wave directional Doppler evaluation of the common, internal and external carotid arteries. The majority of patients included in this study were referred to the Vascular Laboratory because of a history of transient ischaemic events or minor stroke with good recovery, but some patients with an asymptomatic carotid bruit were included.

Patients were submitted to angiography on clinical indications alone, and the decision to proceed to angiography was not based upon the results of the noninvasive tests. Angiography was carried out in patients with one or more episodes of carotid territory transient ischaemic attacks, amaurosis fugax, carotid territory reversible ischaemic neurological deficits, and carotid territory stroke provided the latter underwent a major degree of recovery. Angiography was not normally undertaken in patients totally unfit for surgical therapy, patients over 75 years of age and patients whose clinical presentation was a pure vertebrobasilar episode with totally normal noninvasive studies. Patients were included in this study only if the noninvasive tests preceded angiography.
diagnosis was angiographically determined prior to referral to the Vascular Laboratory were excluded from this study. Noninvasive tests were performed prior to angiography. The angiography was undertaken and reported independently and blind to the results of the noninvasive study and the two were compared only after the angiographic reporting had been completed.

One hundred and fifty four patients met the above criteria and have undergone conventional contrast arteriography yielding a total of 300 contrast investigations (sides) of good diagnostic quality for inclusion into the study. Of these, forty four carotid arteries were unequivocally documented as being totally occluded in 42 patients (two bilateral occlusions), the incidence of occlusion for the angiographically investigated patients being 15%.

Carotid phonoangiography was carried out with a split frequency display (Kartchner and McRae, Narco Biosystems). The presence of a bruit of greater than 75% of systole over the carotid bulb or internal carotid, or the absence of heart sounds propagated into the upper neck was recognised as abnormal. Directional Doppler evaluation of the supraorbital artery was done with a Medasonic D9 Doppler using compression of the superficial temporal and facial arteries, but not common carotid compression. Direct directional Doppler evaluation of the carotid artery was performed with the same unit, recording advancing and receding channels on separate channels of a two channel recorder (Medasonic R12A). A recording was obtained over the common carotid artery in the neck, and the Resistance Index calculated. A value of > .80 was accepted as abnormal. Recordings of the velocity signals were made over the carotid bulb, external and internal carotid arteries. Normally forward (cranial) flow only is detected in these recordings, with activity being recorded in only the cranially directed Doppler channel. The presence of in-phase activity of the reverse channel, simultaneous to the expected activity in the forward channel, was taken to indicate turbulence, and a Turbulence Index could be obtained by dividing the magnitude of the reverse channel by the magnitude of the forward channel activity. The presence of a Turbulence Index > 0.30 was interpreted as being indicative of either a stenosis of 35% or greater or the presence of abnormality producing turbulence in the vessel being insonated. The internal carotid artery Doppler signal has a distinctive character with a high flow rate in diastole as well as systole, and a technician can easily recognise this vessel and distinguish it from the external carotid artery. The absence of a distinct internal carotid signal was interpreted as a strong indication of the presence of a tight internal carotid stenosis, or of total occlusion of the internal carotid artery.

The components of this battery of tests that indicate major pressure/flow reduction in the carotid artery, namely an abnormal supraorbital test or a high resistance index, were recognised as indicators of a possible occlusion. When the internal carotid signal was absent in the presence of one or both of these abnormalities, a confident diagnosis of carotid occlusion was normally made.

Carotid arteriography was performed in all cases by the Seldinger route. Where arch angiography did not provide good quality diagnostic films, selective carotid studies were always performed. Two independent observers each confirmed the diagnosis of total occlusion of the internal carotid artery.

The individual and combined results of the noninvasive tests were compared with the angiographic finding of total internal carotid artery occlusion in the positive group. All nonoccluded vessels constituted the nonoccluded group for the purpose of this study.

In ten patients a confident diagnosis of occlusion was made on the basis of the results of the noninvasive test. These patients either did not meet our criteria for angiography or refused to undergo angiography.

Results

Angiography

Of the total series of 300 carotid angiograms performed independently of the noninvasive tests, 256 carotid arteries were documented angiographically to be patent with varying degrees of stenosis being present. Of these 151 carotid arteries had little or no stenosis present, while a further 105 had between 35% and 95% stenosis. These constituted the nonoccluded group. A total of 44 carotid arteries were documented to have occlusion in 42 patients (bilateral occlusion in two patients) out of the total series of 300 carotid angiograms. In one case a confident radiological diagnosis of occlusion was reviewed when the subsequent comparison with the noninvasive test indicated a high grade of stenosis, and in this case repeat selective arteriography confirmed the presence of a tight internal carotid stenosis.

Resistance Index

The Resistance Index was elevated above 0.80 in 28 of the 44 occlusions, yielding a sensitivity of 64% for the diagnosis of occlusion for this one test. Nine false positives for occlusion in 256 patients gave a specificity of 96% (table 1).

Phonoangiography

Evaluation of the transmission of heart sounds (table 2) was abnormal in only 14 cases with 29 false positives, while a carotid bruit of >75% of systole was present in 8 cases of total carotid occlusion (table 3). Carotid bruit was therefore only 18% sensitive as a marker for carotid occlusion, with a high false positive
rate of 58 to 256 patent carotids. Although 20 of the 43 patients were referred to the laboratory with a diagnosis of a carotid bruit, only 8 of these bruits proved to be from the carotid bulb.

Supraorbital Doppler
An abnormal supraorbital Doppler was present in 37 of the 44 occluded carotids, yielding a sensitivity for this test of 84% (table 4). Thirty seven false positives for occlusion were due in the most part to carotid stenosis of >50% in the ipsilateral internal carotid artery.

Turbulence Index
This investigation was positive in only 8 of the occluded carotids (table 5) for a sensitivity of only 18%.

Internal Carotid Signal
An internal carotid signal was absent in 31 of the 44 occlusions yielding a sensitivity of 70% (table 6) for this test. In 13 cases the external carotid signal was mistakenly identified as the internal carotid artery. In 7 cases the internal carotid signal was not detected where the vessel was not totally occluded, for a specificity of 97%.

Overall Test
In the presence of tests suggesting a high grade stenosis, i.e. a high Resistance Index and/or abnormal supraorbital test, the absence of an internal carotid signal was usually taken to indicate a total internal carotid occlusion. Although all 44 occlusions were detected by the battery of tests as being high grade pressure reducing lesions, in only 31 of the 44 carotids was a confident diagnosis of total occlusion of the carotid artery made on the basis of the noninvasive tests, for a sensitivity for the battery of 70% (table 7). Only 5 false positive diagnoses of occlusion were made for a specificity of 98% for this diagnosis.

The contributions of the important tests to the diagnosis of total carotid occlusion are examined in table 8. The presence of a high resistance index, absent internal carotid signal and abnormal supraorbital test was the most frequent finding, followed closely by the combination of absent internal carotid signal and abnormal supraorbital test.

Discussion
The relative sensitivities and specificities of the individual tests appear poor at first examination, but it must be remembered that these tests were selected for their ability as a battery to detect haemodynamically significant carotid stenosis, and not specifically for the detection of occlusion. In a previous study10 investigating the accuracy of a similar battery of noninvasive tests, we have demonstrated a 95 percent sensitivity and 95 percent specificity for stenosis of greater than 50 percent of the carotid artery. Based on this previous work we have assumed that a totally normal noninvasive test makes the possibility of a high grade carotid lesion highly unlikely. For this reason we have not normally proceeded to angiography in patients with pure vertebrobasilar symptomatology and totally normal carotid noninvasive studies. A positive result for high grade stenosis in all of these patients confirms the effectiveness of the battery in performing its primary function. However, in only 31 of the 44 tests carried out on occluded carotid arteries was the operator confident enough to firmly diagnose a total occlusion in the current study.

The most common cause of uncertainty in diagnosing the occlusion in this group of patients was the presence of a signal from the external carotid which was mistaken for the internal carotid. The presence of a high diastolic flow in the external carotid in patients
with internal occlusion results from the high flow in the external carotid which in these circumstances supplies the brain via the various collateral vessels. Information of the external carotid thus may easily be mistaken for the internal carotid. A second common cause for uncertainty was the presence of a bruit arising from the carotid of > .75 of systole. Such bruits normally only arise from the internal carotid, external carotid bruits of shorter duration and higher pitch. In most instances the external carotid bruit will diminish in intensity if the superficial temporal artery is compressed, and this can be used to identify the site of origin of the bruit. In four of our cases, however, a bruit arose from a diseased common carotid artery immediately proximal to the carotid bulb, and caused a mistaken diagnosis of a high grade stenosis.

In general, patients with internal carotid occlusion do not present with carotid bruits and this explains the low sensitivity of phonoangiography and turbulence index in detecting occlusion. In this series 20 of the cases were noted to have cervical bruits, but only 8 of these arose from the carotid, the balance were radiated from the base of the neck or heart. In 4 cases the bruit arose from the external carotid and in a further 4 cases the bruit arose from common carotid disease.

No predominance of side was noted in the occurrence of occlusion, with 23 left and 21 right sided occlusions being present.

The triad of a high resistance index, absent internal carotid signal and abnormal supraorbital test was present in 14 cases. An absent internal carotid signal associated with either or both of these other two abnormal tests was present in 32 of the 44 cases. On the basis of these findings, the absence of an internal carotid artery signal when associated with either a high resistance index or an abnormal supraorbital test, should strongly suggest the presence of an occlusion of the internal carotid artery.

In the total series of 300 cases, only 5 false positive cases occurred where a diagnosis of total occlusion was made on the basis of the above triad of positive tests in 4 patients, and an abnormal supraorbital and absent internal signal in the fifth case. This high specificity of 98% appears to be highly satisfactory until one examines closely the angiographic findings of these 5 patients. In each case the false positive diagnosis of occlusion was demonstrated by angiography to be a very tight carotid stenosis, and each of these patients required carotid endarterectomy for the treatment of recent transient ischaemic events. The fact that all five patients with false positive tests required surgery highlights the potential unfavourable consequences of labelling a patient as having an occlusion purely on the basis of a noninvasive test, thus missing a potentially surgically correctable tight stenosis. This is particularly applicable to noninvasive tests with a high false positive rate where a high degree of stenosis is frequently misdiagnosed as an occlusion. 11

A further factor of importance is the relatively high proportion of patients that require surgery in patients with carotid occlusion. In our series 9 cases required surgery, 4 requiring external carotid endarterectomy for symptomatic external carotid stenosis, 3 internal carotid endarterectomy of the opposite side, 1 for repair of a traumatic false aneurysm, and 1 for removal of a carotid body tumour.

Although the overall sensitivity of the battery in diagnosing total internal carotid artery occlusion was 70 percent, this figure does not take into account the 10 patients in whom a confident diagnosis of occlusion on noninvasive tests could not be confirmed angiographically. Therefore, it must be conceded that the actual sensitivity of this battery for diagnosing internal carotid occlusion may be inaccurate. In view of the relatively poor sensitivity of the battery of noninvasive tests in the diagnosis of total carotid occlusion, and in view of the high proportion of cases which require surgery when occlusion is in fact present, we are unable to support the use of noninvasive tests alone in the diagnosis of total internal carotid occlusion. The uniform requirement for surgical management in cases with false positive test for occlusion further argues for an-

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**Table 6** Absent Internal Carotid Signal in the Detection of Carotid Occlusion

<table>
<thead>
<tr>
<th>Internal carotid signal</th>
<th>Signal present</th>
<th>Signal absent</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angiogram</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not occluded</td>
<td>249</td>
<td>7</td>
<td>256</td>
</tr>
<tr>
<td>Occluded</td>
<td>11</td>
<td>33</td>
<td>44</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>75%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specificity</td>
<td>97%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 8** Contribution of Individual Tests to Positive Findings in Keeping with Carotid Occlusion in 44 Occlusions

<table>
<thead>
<tr>
<th>Number cases</th>
<th>High RI</th>
<th>Absent internal</th>
<th>Abnormal supraorbital</th>
<th>Number with bruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>+</td>
<td>+</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>+</td>
<td>+</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>+</td>
<td></td>
<td>+</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>+</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>+</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 7** Analysis of Confidently Diagnosed Carotid Occlusions on the Basis of Noninvasive Test Battery

<table>
<thead>
<tr>
<th>Diagnosis of occlusion</th>
<th>Not diagnosed</th>
<th>Diagnosed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angiogram</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not occluded</td>
<td>251</td>
<td>5</td>
<td>256</td>
</tr>
<tr>
<td>Occluded</td>
<td>13</td>
<td>31</td>
<td>44</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>70%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specificity</td>
<td>98%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
giographic confirmation of the diagnosis of occlusion in all cases.

However, we have found the performance of the noninvasive battery to have a useful role in enabling prediction of the angiographic anatomy, thus allowing more precise planning of the angiographic procedure. In the situation where all three components of the triad of absent internal carotid signal, abnormal supraorbital test and high resistance index are present, in order to prevent overlooking a critically tight stenosis, a selective carotid study should be planned. If an arch study, particularly with unsatisfactory anatomic resolution, suggests occlusion, and the noninvasive tests do not support this finding, selective carotid angiography is mandatory to establish the true anatomy. If an occlusion is suspected on noninvasive testing, but a bruit or positive turbulence index confuses the result, the subsequent angiographic procedure must give special attention to excluding the presence of common carotid stenosis, external carotid stenosis or a significant blind proximal stump of the thrombosed internal carotid artery.

This simple and inexpensive battery of noninvasive tests taking less than 30 minutes allows a better pre-angiographic appreciation of the functional status of the extracranial circulation without adding to morbidity or major cost, and should be seen not as replacing angiography in this condition, but rather as a complementary examination to arteriography.

Acknowledgment

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References

The value of noninvasive investigation in the diagnosis of total occlusion of the internal carotid artery.
L J Levien, C L Voll, P Lithgow-Jolly and V U Fritz

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