Carotid Compression Tonography

Correlation With Bilateral Carotid Arteriography in the Diagnosis of Extracranial Carotid Occlusive Disease

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Abstract:
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- One hundred twenty-two patients had carotid compression tonography (CCT) followed by bilateral carotid arteriography. In the group (82 patients) which was felt to have significant occlusive disease of the internal carotid at the level of the carotid bifurcation (>50% stenosis), the CCT showed a 92% correlation with arteriography. Of the group (48 patients) that underwent endarterectomy, there was a 94% correlation with CCT testing. In 40 patients, with normal arteriograms or with less than 50% stenotic lesions on arteriography, there was a large number (25%) of patients with a CCT test which appeared to indicate decreased flow. Various reasons for this are discussed.

The high correlation of the CCT test and carotid arteriography in the patients with surgically amenable lesions would suggest that the CCT test is a good noninvasive screening technique for the detection of significant occlusive disease of the extracranial carotid vascular system.

Additional Key Words
- intraocular pressure
- carotid endarterectomy
- carotid artery stenosis
- embolic disease
- ophthalmodynamometry
- noninvasive screening test
- crossover flow

The diagnosis of occlusive disease which can compromise the lumen of the carotid arteries is a serious challenge to many specialties.1 The carotid arteriogram is useful in the investigation of possible anatomical factors that could account for a physiological reduction in cerebral blood flow. The vascular surgeon must depend upon the arteriogram to develop his plan for surgical intervention. However, many clinicians are hesitant to order this study because of the attendant risks. In the largest study to date, the grave complication rate from arteriography was documented at 1.2%.2

Because of this dilemma a noninvasive screening test has been sought that would hopefully identify those patients that should undergo arteriography. Several such tests have been devised. These include ophthalmodynamometry (ODM),3 ophthalmodynamography,4 carotid compression tonography (CCT),5 and Doppler sonography.6

Two noninvasive tests are being performed at The Cleveland Clinic Foundation as adjunctive studies in the diagnosis and management of patients with carotid vascular disease. One is ophthalmodynamometry which measures and compares the ophthalmic artery pressure of each eye.7 These pressures, in turn, allow a presumptive comparison to be made between the distal perfusion pressure of each internal carotid artery. A comparison of the correlation of the results of ODM, CCT and carotid arteriography will be the subject of a subsequent report.

The second test is carotid compression tonography. This test, as described by Barrios and Solis,4 records volume adjustments within the vascular space of each eye in association with carotid compression. The changes in blood volume of the eye with carotid compression are directly related to changes in intraocular pressure. Analysis of continuous dynamic changes in intraocular pressure by tonography provides physiological data about the contribution each carotid makes to the blood flow in each respective ophthalmic artery and subsequently to the posterior ciliary arteries and to the choroidal vascular space of each eye. In addition, the tonographic data provide a permanent recording which is made a part of the patient’s chart. This record can be scrutinized by several individuals making the interpretation less subject to bias.

In this study, we compared the results of arteriography with carotid compression tonography to determine what role this noninvasive test might have in the diagnosis and management of patients with carotid vascular disease.
Methods
Between April 1972 and March 1974, 360 patients had a carotid compression tonography test performed as part of their evaluation by the neuro-ophthalmology section of the Department of Ophthalmology. The majority of these patients were seen in consultation at the request of the Department of Vascular Surgery or the Departments of Neurology and Neurosurgery for evaluation of possible vascular disease involving the extracranial carotid vascular system.

All of the 360 patients had a complete ophthalmic and neuro-ophthalmic examination, including Goldmann perimetry and ophthalmodynamometry whenever possible.

One hundred twenty-two patients in this group had bilateral carotid arteriography after their CCT test had been performed. These 122 records were reviewed consecutively to compare the results of carotid compression tonography with arteriography. The arteriograms were reviewed separately by members of the Vascular Surgery and Radiology Departments. The degree of stenosis in the carotid artery was calculated by tracing the diameter of the radiopaque column at its narrowest point in the affected segment of the carotid artery onto an overlay. Using this same tracing, the diameters of the artery at the area of stenosis were drawn by connecting lines from the nearest proximal and distal segments of the artery not affected by the stenotic lesion. The diameters were then measured using a micrometer. The ratio between the diameter of the normal arterial wall and the diameter of the radiopaque column at the site of stenosis was then determined and expressed in terms of percent stenosis.

The CCT tests were all performed and interpreted by one of us (D.N.C.) in the Ophthalmology Department. The carotid compression tonography test was performed as follows: All CCT recordings were made with an electronic recording tonometer (Mueller) on standard recording paper. For a more thorough analysis of the tracings, the gear ratios were modified to provide a paper speed of four inches per minute. Recordings of intraocular pressure were performed continuously, as in conventional tonography, before, during, and after compression of the common carotid artery in the neck.

The presence of pressure waves in the tonogram is essential. Their absence indicates a faulty technique or machine malfunction. The amplitude of this ocular pulsation was carefully checked before, during, and after carotid compression. A diminutive pulse was a well-recognized indication of carotid insufficiency. Ocular pulsations were commonly observed to decrease in normal subjects during compression of the ipsilateral common carotid.

Compression was always exerted at the proximal or lowest portion of the common carotid artery to avoid a vagal or hypotensive systemic response by inadvertent pressure on the carotid body. Compression well below the carotid bifurcation also decreased the chance of dislodging atheromata from the arterial lumen, since atheromata have a predilection to form at the bifurcation. For standardization the test always began with tonography of the right eye. Within a few seconds the recording ink pen stabilized and recorded a steady ocular pulse and pressure level. The right common carotid was then compressed, just above the clavicle, with the fingers of the examiner’s hand. At that moment, in a normal subject, the intraocular pressure fell rapidly. Compression was maintained until the pressure no longer decreased rapidly, usually from four to six seconds but never longer than eight seconds. Compression was then suddenly and completely released. With the recorder remaining on the right eye, compression was then applied to the left common carotid. The next step was to place the electronic tonometer on the left eye while the left and then the right carotid were compressed in appropriate sequence (fig. 1).

Three parameters were used to interpret the CCT test. The amplitude of pulsations was one indication of carotid system flow, particularly when there was a difference between the two sides. Even a slight difference between the two sides was significant and easy to measure. Bilaterally diminished pulsations may have been a sign of decreased carotid flow, but were not as reliable a sign since a decreased cardiac output or decreased pulse pressure may have produced the same finding.

The next logical parameter might seem to be the slope of the fall in intraocular pressure with compression. However, this fall was dependent on many factors. For instance, the slope of the fall can be varied by outflow through the vortex and ciliary veins as well as collateral circulation to the ophthalmic artery. If the patient has a thick muscular neck the fall in intraocular pressure can also be retarded.

Normal carotids. Upper tracing shows the continuous tonographic recording of the right eye. These are good ocular pulsations. Right carotid compression (RCC) produces a large fall and a rapid recovery in intraocular pressure within the right eye. Contralateral or left carotid compression (LCC) does not cause a fall in intraocular pressure in the right eye. (There is no crossover in the normal situation.)

Lower tracing of the lonographic recording of the left eye shows an identical normal pattern.
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The slope of the recovery phase of intraocular pressure which occurred immediately after release of the compression appeared to be dependent only on the flow of blood from the point of compression to the choroidal vascular space. This served as the second reliable parameter.

The third parameter was based on the flow changes that occurred when the contralateral carotid was compressed (while the tonometer remained on the right eye, the left carotid was compressed). If there was a significant contribution to the intraocular pressure from the contralateral carotid, there would be a drop in intraocular pressure when the opposite carotid was compressed. This was called the "crossover" or crossfilling sign. When present, it was indicative of participation of the opposite carotid in filling the choroidal vascular space of the recorded eye. The amplitude and slope of the fall and of the return of intraocular pressure with contralateral carotid compression were an indication of the quantity of the total supply of blood going to the recorded eye from the contralateral carotid (compare figs. 2 and 3). When severe stenosis was present bilaterally, we would occasionally see bilateral crossover. Bilateral crossover had been seen more commonly with severe bilateral carotid stenosis in conjunction with varying degrees of vertebral occlusion.

If there was a definite marked decrease in flow via the ipsilateral carotid with no crossover, and if there were no ischemic ocular changes, we made the assumption that the collaterals were being derived from the posterior circulation. This was confirmed on several occasions by selective vertebral angiograms performed via the transfemoral route in patients in this study.

Results

The study included 122 patients, 77 men and 45 women. Eighty-two patients were found to have a 50% or greater stenosis in one or both carotid arteries by arteriography. The CCT test demonstrated decreased flow on the most stenotic side in 76 of the 82 patients, giving a 92% correlation with arteriography.

Forty-eight of these 82 patients were candidates for surgical intervention and subsequently underwent carotid endarterectomy. Of the 48 patients, 45 or 94% had a positive CCT test.

In 6 of the 76 cases, the CCT test was normal. Arteriography in these six patients demonstrated a 55% to 60% stenosis in two, a 75% stenosis in one, an 85% stenosis in one, and occlusion in two (table 1).

In the remaining 40 patients in the study, carotid

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[FIGURE 2]
Stenosis (70%) of the right internal carotid. Upper recording of the right eye shows a diminished ocular pulse. Right carotid compression (RCC) results in a more gradual fall and a prolonged recovery after release. A small fall and recovery are produced in the intraocular pressure of the right eye by left carotid compression (LCC). (This shows the existence of significant collateral blood flow supplying the right eye from the left carotid system.)

Lower recording of the left eye is normal with carotid compression.

[FIGURE 3]
Occlusion of the right internal carotid. Upper recording of the right eye shows a very poor ocular pulse. Right carotid compression (RCC) produces no fall in intraocular pressure. Left carotid compression (LCC), however, produces a marked fall and recovery in the intraocular pressure of the right eye. (This demonstrates that the major portion of blood flow to the right eye is being supplied by the left carotid system.)

Lower recording is normal for comparison.

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arteriography was either completely normal or showed stenotic lesions of 50% or less (usually <20%). Of these 40 patients, the CCT test was also normal in 30 (75% positive correlation). The CCT was felt to demonstrate decreased flow in 10 (25%) of the 40 patients with “normal” arteriograms.

**Discussion**

From an analysis of the data in the study some conclusions can be drawn regarding the validity and the level of confidence of CCT testing.

There appeared to be a good correlation between the CCT test and arteriography. In patients who had a 50% or greater stenosis in one or both carotid arteries, the CCT test indicated decreased flow on the most stenotic side in 92% of the cases.

In this study, six cases (8%) with “significant” stenosis as measured by angiography showed a normal flow pattern with CCT testing. In two of these cases there was occlusion of the involved internal carotid. The basis for this normal flow pattern may be due to multiple external to internal carotid anastomoses, which are physiologically significant and are known to develop after internal carotid occlusion. The fact that the CCT test indicated normal flow in these cases may itself be significant. For example, if the CCT was normal or showed normal flow to the eye on the same side as an occluded internal carotid artery, the prognosis for such a patient may be better than for a similar patient with an occluded internal carotid with decreased flow by CCT. We have no data to support this hypothesis, but it is an intriguing possibility.

In the 40 patients with “insignificant” or no demonstrable stenosis in their carotids by arteriography the CCT test showed a positive correlation in 75% (normal arteriogram and normal CCT). Twenty-five percent showed a negative correlation, normal arteriogram, and a CCT test which indicated decreased flow. It is also important to note that those patients who demonstrated a unilateral flow decrease by CCT and subsequently had a normal carotid arteriogram were all being evaluated for symptoms or signs of cerebrovascular insufficiency. The failure of the arteriogram to demonstrate the anatomical etiology to account for the decreased flow does not mean that the flow decrease is significant. Arteriography enables a percentage estimate of the actual size reduction of the arterial lumen at the site of the stenotic lesion. This calculation is then used to predict whether or not the stenotic lesion has the potential to decrease arterial blood flow. Recently, Kartchner et al.10 have published data comparing intra-arterial carotid blood flow measurements using a flowmeter at the time of endarterectomy with the arteriographical interpretation of these same stenotic lesions. In their study, arteriography falsely predicted a hemodynamically significant lesion in 7 of 52 (13%) stenotic lesions. Of 17 lesions considered insignificant by arteriography, 3 of the 17 (18%) were found at the time of surgery to be significantly reducing arterial blood flow. Thus, even for a study as highly respected as carotid arteriography, there is a significant degree of false-negatives (13%) and false-positives (18%) when compared to actual blood flow.

Unless the patient undergoes an aortic arch arteriogram, significant stenotic lesions at the origin of the brachiocephalic vessels will be missed entirely. Furthermore, it is often quite difficult to interpret stenosis within the interosseous portion of the internal carotid because of lack of radiographical contrast. In addition, the ophthalmic artery or posterior ciliary vessels may be obstructed but might not be detected by arteriography because of their small size. All of these factors might have played a role in unilaterally decreasing the blood flow to one eye accounting for a “positive” CCT and a “normal” carotid bifurcation.

Until recently, ophthalmodynamometry (ODM) has been the best noninvasive method available, but a number of authors have pointed out its limitations.11,12 In addition, there are a number of situations in which the ODM cannot or should not be performed. The CCT test, on the other hand, is not limited by these factors (table 2).

Carotid compression tonography appears to be a safe procedure to perform. In our series of more than 360 patients there have been no complications. One of

**TABLE 1**

<table>
<thead>
<tr>
<th>Degree of Stenosis (%)</th>
<th>No. pts.</th>
<th>CCT Test (+) Correlation</th>
<th>CCT Test (-) Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 or more</td>
<td>50</td>
<td>48</td>
<td>2</td>
</tr>
<tr>
<td>80 to 89</td>
<td>15</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>70 to 79</td>
<td>7</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>60 to 69</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>50 to 59</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>82</td>
<td>76</td>
<td>6</td>
</tr>
</tbody>
</table>

**TABLE 2**

**Considerations for CCT Test (When ODM Contraindicated or Not Possible)**

1. Central retinal artery occlusion
2. Recent ocular surgery
3. Media opacities
   (a) vitreous hemorrhage
   (b) cataractous lens
   (c) inflammatory membranes
4. Corneal opacities or irregularities
5. Small pupils (i.e., miotic therapy)
6. Anticoagulant therapy
7. Diabetic retinopathy or other vascular retinopathies that could bleed from localized external pressure
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us (D.N.C.) in a previous series of 100 patients at another hospital had one transient complication. A 75-year-old man with carotid stenosis experienced numbness of the left arm lasting one-half day. There was no residual deficit on subsequent neurological examination. This was at a time when compression of the carotid was being applied higher in the neck. At the Neurological Institute in Montevideo, Uruguay, Barrios had reported performing this test on more than 1,500 patients and had encountered no complications. It is important to note that compression is carried out low in the neck to avoid the carotid sinus, and compression is maintained for only four seconds and never longer than eight seconds. There is a very remote risk to patients undergoing carotid compression in a testing procedure. Two deaths have been reported in the literature. In both cases, compression was maintained for 15 to 20 seconds — a much longer period than used with CCT. In both cases the compression was done high in the neck and compression was specifically maintained long enough to reproduce neurological symptoms.

There are limitations to using CCT as a test to determine significant extracranial carotid occlusive disease. At present, a reduction in carotid flow by CCT should indicate arteriography. However, the corollary is not true. A normal CCT test cannot be used as evidence to exempt the patient from carotid arteriography in all cases.

For instance, the CCT may fail to show evidence of decreased flow when embolic phenomena from an eroded atheromatous plaque are causing signs and symptoms. Even a plaque which occludes only 10% of the carotid lumen might conceivably give rise to emboli. DeWeese has pointed out that a vessel of the caliber of the carotid must have a 47% stenosis before flow is affected. Smaller plaques do not reduce flow and will not be detected by CCT (fig. 4). When an embolic pattern of disease is suspected by history or by the presence of signs such as cholesterol or platelet plaques in the retinal arterioles, the patient should be considered for arteriography even if the CCT shows a normal flow pattern.

By using the CCT test we have also been able to obtain pertinent information for the vascular surgeon whose patient is in need of an endarterectomy as well as for postoperative follow-up. Occasionally, lesions occurring simultaneously at both carotid bifurcations may appear to have highly similar degrees of stenosis by arteriography. In these cases, the CCT may indicate which side has the more compromised flow as well as demonstrating crossfilling of the intracranial circulation from one side to the other through the anterior communicating artery. In many of our patients carotid arteriography was not able to delineate this crossfilling. With the added information, the surgeon usually elects to initially operate upon the side which receives the crossfilling from the opposite side, i.e., the more compromised vessel in terms of blood flow by the CCT test.

The CCT test may also have some value in postoperative patients who have had a carotid endarterectomy. We have evaluated ten patients with CCT before and after endarterectomy for a blocked carotid system. In all but one case the flow through the carotid artery system by the CCT test was improved by endarterectomy when compared to the preoperative CCT determination. The exception was in a patient who continued to show a decreased perfusion pattern by CCT in the carotid system that had undergone a "successful" endarterectomy. Subsequently, a repeat carotid arteriogram was performed. The arteriogram revealed an occluded vessel at the site of the endarterectomy.

**References**


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