TO MINIMIZE complications of focal cerebral ischemia following therapeutic carotid artery ligation, it is essential to assess the hemodynamic changes caused by carotid ligation and to monitor them relative to the degree of occlusion. With advances in the technology of Doppler flowmeters, it is possible to detect non-invasively the direction of cerebral blood flow and to visualize the flow pattern in vessels by spectrographic display. We have reported the use of the Doppler flowmeter in the hemodynamic assessment during neurosurgical procedures. Our recent experience with a Doppler flowmeter in patients undergoing gradual carotid occlusion is presented here.

Summary

Hemodynamic changes were examined with an ultrasonic Doppler flowmeter and with a sound-spectrograph in 5 patients with internal carotid giant aneurysms or with recurrent laryngeal cancer undergoing gradual carotid occlusion. The ultrasonic Doppler technique was useful for preoperative assessment of intracranial cross-filling and as a practical guide for the graded reduction of blood flow in the carotid artery. The degree of flow increase in the contralateral carotid artery when the ipsilateral carotid artery was totally occluded was greater in postoperative gradual occlusion than in intraoperative rapid occlusion. In one patient with bilateral internal carotid artery giant aneurysms, whose left internal carotid artery had already been ligated at its origin, gradual occlusion of the right internal carotid artery was performed after the bilateral superficial temporal artery-middle cerebral artery (STA-MCA) anastomoses. Flow in the donor artery of the right STA-MCA anastomosis developed with increasing occlusion of the right internal carotid artery.

Methods

The flowmeter used is a bidirectional ultrasonic Doppler flowmeter with sound-spectrograph (model EUD-4, Hitachi Medical Corporation). The technical aspects of this apparatus have been described in other reports. The transmitted frequency used is 5 MHz.

For detection of the carotid flow signal, the patient was encouraged to relax and was placed supine with his neck slightly extended. His head was rotated 30° away from the side of the examination. The tip of the ultrasonic transducer was placed on the skin with a contact medium for ultrasonic transmission (Aquasonic 100, Parker Laboratories Inc.) or with saline solution on blood vessels during surgery. Before transcutaneous flow studies, the course of vessels under the skin was depicted by tracing the line of detectable flow. The incident angle was set at 60° as precisely as possible on the theoretical and experimental bases that the Doppler signal is minimal around the incident angle of 90°. The tip of the transducer was placed at the same marked points on the skin or vessels in each patient throughout the sequential studies.

Clinical Materials

The clinical pictures of the patients, including the results of angiographic and Doppler flow studies, are summarized in the table. Three were men with recurrent laryngeal cancer and 2 were women with giant aneurysms in the intracavernous portion of the internal carotid arteries. Three had hypertension, one heart disease.

Results

Preoperative catheter cerebral angiography was performed in 4 patients. In 2 of these, significant cross-filling through the anterior communicating artery was demonstrated angiographically with or without contralateral carotid compression; in the remaining 2 no cross-filling was demonstrated. In the third patient, angiography was not performed because transfemoral catheterization was unsuccessful and direct carotid puncture in the neck was not feasible because of the operative wound and the tumor involvement in the neck. In this patient, however, transcutaneous Doppler flowmetry with contralateral carotid compression suggested good collateral circulation, as shown in figure 1. That is, the flow volume of the right common carotid artery increased about 20% on left common carotid compression. As the site of gradual carotid occlusion, the common carotid artery was chosen in all but the fifth patient.

The lower part of figure 2 shows selected results of direct study of blood flow just distal to the Selverstone clamp during an intraoperative trial occlusion in patient No. 3. The flow pattern specific to stenosis, i.e., spectral broadening and increased duration, appeared at a certain degree of occlusion, and it developed sequentially with the increase in the occlusion. Just before flow signals disappeared at the completion of occlusion, the broad spectral flow pattern became short in duration and was accompanied by reverse flow signals.

As shown on the upper part of figure 2, contralateral carotid flow increased with the increase of
the occlusion, reaching about 150% of the control value at the completion of occlusion. After the trial occlusion, the clamp was opened slowly to a position at which the flow pattern returned to normal and was left at this position.

Gradual postoperative closure of the clamp was carried out daily or on every second day by rotation of the stem. The amount of rotation was determined each time in the light of the intraoperative findings as shown in figure 2 and the experimental data on the relation between the degree of stenosis and the flow pattern detected just distal to the stenosis with the Doppler flowmeter. The clamp was closed gradually over a 5- to 14-day period, depending upon the degree of intracranial cross-circulation assessed by preoperative angiographic and Doppler flow studies.

Figure 3 shows selected results of the transcutaneous Doppler flow measurement during the percutaneous postoperative occlusion of the left common carotid artery over 8 days in the third patient. As shown on the lower part of this figure, the flow pattern specific to stenosis was detected just distal to the clamp. The relationship between the amount of clamp closure and the flow pattern detected transcutaneously just distal to the clamp during postoperative transcutaneous occlusion did not correlate with that found in the intraoperative trial occlusion. As shown on the upper part of figure 3, the flow volume of the contralateral common carotid artery increased to about 200% of the preoperative value when the carotid occlusion was completed. This rate of flow increase in the contralateral carotid artery was higher than that found in the intraoperative trial occlusion, which was performed relatively rapidly.

In 2 (patients Nos. 2 and 4) of the 4 who had gradual occlusion of the common carotid artery (table), flow directed from the internal to the external carotid artery was detected by transcutaneous measurement after the completion of common carotid artery occlusion. Flow was small in comparison with that found before occlusion. Flow signals of these vessels were identified and differentiated from those of other vessels on the basis of their anatomical localization in the neck determined by the transcutaneous Doppler flow study before carotid occlusion and compared with the flow patterns specific to the internal or
Gradual Lt Carotid Occlusion by Selverstone Clamp
Intraoperative measurement

**Figure 2.** Doppler flow study during an intraoperative trial occlusion in patient 3. Just distally to the left common carotid artery clamp site (the lower tracing), the flow pattern specific to the post-stenotic region appears at a certain degree of occlusion and this increases with progressive occlusion. The value of relative flow volume measured in the post-stenotic region by the Doppler flowmeter is not quantitatively reliable because the vibration of vessels caused by turbulent flow increment the flow signal to various degrees. Contralateral carotid flow (upper tracing) increased with progressive carotid occlusion, and after the left-sided occlusion was completed, this flow reached a higher value than that before carotid occlusion.

Postoperative Transcutaneous Measurement
Gradual Lt Carotid Occlusion

**Figure 3.** A postoperative transcutaneous Doppler flow study during percutaneous gradual occlusion of the left common carotid artery by Selverstone clamp in patient 3. The flow pattern specific to stenosis develops sequentially with the increase of occlusion just distal to the clamp of left common carotid artery (lower part). The flow volume of the contralateral common carotid artery increases with the advance of occlusion (upper part).
TABLE  Clinical Evaluation of 5 Patients Who Had Gradual Carotid Occlusion

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Clinical diagnosis</th>
<th>Combined diseases</th>
<th>Occluded artery</th>
<th>Angiographically revealed intracranial collateral</th>
<th>Period of gradual occlusion</th>
<th>Flow direction after the completion of occlusion</th>
<th>Complications (Follow up term)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>56</td>
<td>M</td>
<td>Recurrent laryngeal cancer</td>
<td></td>
<td>Rt CC (Rt IC)</td>
<td>(+)</td>
<td>5 days</td>
<td>not detectable</td>
<td>Massive bleeding from carotid artery Cerebral infarction (9 M)</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>M</td>
<td>Recurrent laryngeal cancer</td>
<td>Atrial fibrillation, Hypertension</td>
<td>Lt CC (+)</td>
<td>not examined</td>
<td>6 days</td>
<td>IC → EC</td>
<td>None (12 M)</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>M</td>
<td>Recurrent laryngeal cancer</td>
<td>Lung Tbc</td>
<td>Lk CC not examined</td>
<td>not examined</td>
<td>8 days</td>
<td>not detectable</td>
<td>None (10 M)</td>
</tr>
<tr>
<td>4</td>
<td>57</td>
<td>F</td>
<td>Hypertension</td>
<td></td>
<td>Rt CC (-)</td>
<td>not examined</td>
<td>14 days</td>
<td>IC → EC</td>
<td>None (4 Y 9 M)</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>F</td>
<td>Hyperaldosteronism</td>
<td></td>
<td>Rt IC (+)</td>
<td>(+)</td>
<td>5 days</td>
<td>IC → EC</td>
<td>None (12 M)</td>
</tr>
</tbody>
</table>


In one of these two patients, the reversal of the direction of flow was demonstrated by Doppler flowmetry on the third day after the completion of occlusion. In the remaining 2 patients, flow identifiable with the internal or external carotid artery could not be detected transcutaneously.

Figure 4 shows the results of transcutaneous Doppler flow measurement at 3 different clinical stages of bilateral superficial temporal arteries (STAs) in patient 5 who had bilateral internal carotid giant aneurysms. On admission, the left internal carotid artery had already been ligated and the STA flow was normal both in volume and in flow pattern on both sides (fig. 4 left).

After bilateral STA-MCA anastomoses (fig. 4 middle), the left STA flow increased prominently and

![Figure 4: Transcutaneous Doppler flow measurements of bilateral superficial temporal arteries (STAs) at 3 clinical stages. After bilateral STA-MCA anastomoses, the flow in the left STA increased significantly with the application of contralateral carotid compression as shown in the middle bottom tracing. U = Instantaneous mean flow velocity.](http://stroke.ahajournals.org/)

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its flow pattern changed from external carotid type to internal carotid type. In the right STA, the flow pattern changed but flow volume was little affected. The gradual occlusion of the right internal carotid artery was started on the 13th day after the STA-MCA anastomoses. After ligation of the right internal carotid artery, STA flow on the right also increased prominently and the flow pattern changed to internal carotid type. Consequently, flow in the STA in patient 5 increased 5 fold on the right and about 6 fold on the left in comparison with flow values on admission. Flow patterns of typical internal carotid type were found on both sides (fig. 4 right).

Figure 5 shows the results of transcutaneous flow measurements of the right STA, the donor artery of the STA-MCA anastomosis, in patient 5 during the intraoperative trial occlusion of the right internal carotid artery. Flow increased with the increase of ipsilateral internal carotid occlusion, reaching about 160% of the value found before carotid occlusion.

The postoperative course was uneventful in all but patient 1 whose common carotid artery ruptured at the site of clamping after completion of the clamp closure. The vessel was ligated as an emergency measure. Three days later, the internal and external carotid arteries were also ligated at their origin in a radical operation for laryngeal cancer. On the day after the operation, left hemiplegia developed, but it progressively improved.

Discussion

Gradual ligation of the carotid artery is almost always preferable to rapid occlusion because of the lower incidence of neurological complications.\(^7\) In patient 3, gradual occlusion gave a higher rate of flow increase in the contralateral carotid artery than rapid occlusion, which supports gradual occlusion.

In spite of the relatively high risk, internal carotid artery ligation must occasionally be performed because common carotid artery ligation is not feasible. Recently, some\(^15\) have employed a prophylactic extracranial-intracranial bypass in an attempt to reduce the ischemic complications in patients whose intracranial internal carotid artery aneurysms were managed by internal carotid ligation. The effectiveness of STA-MCA anastomosis in combination with internal carotid artery ligation was substantiated hemodynamically by Doppler flow measurements in patient 5. The combined operations are of value where there is insufficient intracranial collateral circulation or with bilateral carotid occlusions, as in patient 5.

Gradual carotid ligation is usually performed by turning the stem of the clamp a quarter up to one full turn at each interval in the light of the findings of intraoperative intra-arterial pressure measurement,\(^8\) electroencephalography,\(^14\) or regional cerebral blood flow measurement.\(^12\) As shown in previous studies,\(^7\) the distal intravascular pressure and flow volume in the carotid artery distal to a stenosis do not change until the lumen is severely constricted, at which point further minimal reduction in the lumen is associated with marked decreases in both flow and pressure. Therefore, the number of turns of the clamp stem is not a reliable index for precise gradual occlusion. One turn will not produce a constant degree of occlusion even in the same vessel. This report indicates the usefulness of the ultrasonic Doppler flowmeter with sound-spectrograph as a nontraumatic, fast and easily repeatable means of examining hemodynamics in the right STA gradually increased. Divisions on the abscissa are 1.0 sec.

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**Gradual Rt Carotid Occlusion**

**Bilat. STA-MCA anastomosis**

**Rt STA**

![Figure 5. A transcutaneous Doppler flow study in patient 5 of the right STA, the donor artery of the right STA-MCA anastomosis, during intraoperative trial occlusion of the right internal carotid artery. With the increase of right carotid artery occlusion, the flow of the right STA gradually increased. Divisions on the abscissa are 1.0 sec.](image-url)
patients having gradual carotid ligation. The use of this Doppler flowmeter allows adjustment of the degree of occlusion easily and non-invasively by monitoring the flow pattern by sound-spectral analysis of Doppler-shifted signals at the post-stenotic region. The flow pattern change specific to the post-stenotic region is ascribed to jet flow, turbulence, vortex flow, etc. and appears in lower degrees of stenosis than the change of distal intravascular pressure or flow volume.

Some authors\(^8\)\(^-\)\(^10\) have stressed the usefulness of monitoring ipsilateral retinal artery pressures during the daily closure of the clamp as the only way presently available to maintain control over the distal pressure changes. The combined use of nontraumatic techniques — Doppler flowmeter, including Doppler imaging apparatus,\(^7\) ophthalmodynamometer and rCBF study by the xenon inhalation technique\(^13\) will help facilitate safe gradual carotid occlusion.

**References**

Ultrasonic Doppler assessment of hemodynamics in gradual carotid ligation.
K Moritake, H Handa, Y Yonekawa, Y Takebe, S Kishimoto and K Makimoto

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