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Noninvasive Evaluation of Extra-/Intracranial Anastomoses by Dynamic CT and Doppler Sonography

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In order to find a reliable noninvasive method of evaluating patency and function of extra-/intracranial arterial bypass, pre- and postoperative angiograms were compared with the results of pre- and postoperative dynamic computed tomographic (CT) scans and Doppler sonographic findings. Doppler sonography alone is a reliable method for determining patency and relative function of the anastomosis. Dynamic CT permits qualitative evaluation of cerebral perfusion and, by comparison of pre- and postoperative scans, assessment of the contribution of the extra-/intracranial bypass to the circulation of the affected hemisphere. Combined use of Doppler sonography and dynamic CT provides sufficient information about the postoperative status of cerebral perfusion to obviate the use of conventional angiography in routine cases.

Invasive studies, particularly angiography, place increased risk on patients who are candidates for extra-/intracranial (EC–IC) arterial bypass surgery [1, 2]. Since the bypass procedure is still under scientific evaluation [3], additional risk should be avoided if possible. This is particularly true for postoperative follow-up studies.

In order to find a noninvasive method of assessing indications for and effects of EC–IC anastomosis, we performed bidirectional Doppler sonography in a series of 74 patients who underwent EC–IC bypass surgery. Indications for bypass surgery were transient or minor permanent neurologic deficits attributable to a hemodynamically significant stenosis or an occlusion of the internal carotid artery or the middle cerebral artery. The operation was performed 4–10 weeks after the ischemic event to avoid the phase of luxury perfusion. In 17 of the patients, conventional dynamic CT scans were also obtained pre- and postoperatively. The findings of both methods were correlated with pre- and postoperative angiograms.

Subjects and Methods

All 74 patients underwent pre- and postoperative angiography and Doppler sonography. While preoperative angiography usually was performed within 1 month before surgery, postoperative angiography was performed in our center by the standard transfemoral route within 3 months after surgery and only rarely within the first 2 weeks. The criteria used to evaluate the function of the EC–IC bypass were (1) the number of cortical arteries irrigated by the donor artery; (2) the postoperative change(s) in diameter of the donor artery; and (3) blood flow through the bypass in comparison with other extracranial vessels. For the purpose of this study, these criteria were integrated into a scoring system and bypass function was graded on a scale from 0 (occluded) to +++ (patent).

Doppler Sonography

Doppler sonography usually was performed on the day before surgery, at 1 week after surgery, and again at the time of postoperative angiography. All Doppler studies were performed with a bidirectional continuous-wave Doppler velocimeter (Debimetre Ultrasonic, Delalande) with an emitting frequency of 4 MHz. In addition to the routine Doppler studies, preoperative assessment was made of the flow through the branches of the superficial temporal artery. Postoperative Doppler studies included a detailed examination of flow curves in both branches of the superficial temporal artery, particularly the anastomosed branch, applying the following criteria: (1) whether the extracranial donor artery pulse could be detected up to the craniotomy site; (2) whether the blood flow characteristics in the donor artery had changed from "external carotid type" to "internal carotid type;" (3) whether the pulse signal at the craniotomy site could be interrupted by digital compression of the donor artery proximal to the flow probe; and (4) whether compression of the nonanastomosing branch had any effect on the flow in the main artery. Again, these criteria were used in a scoring system and bypass function was graded from 0 to +++.

Dynamic CT

Seventeen of the 74 patients underwent dynamic CT on the day before surgery and after the operation. In patients with bilateral operations, at least two studies were performed. The various intervals between surgery and postoperative CT were 1 week (eight patients), 2–4 weeks (seven patients), and 2 and 3 months (one patient each). Dynamic CT was performed on a Siemens Somatom 2 scanner with a matrix of 256 × 256. Slice thickness was 8 mm; scanning time was 5 sec with an interscan delay time of 3.5 sec. This resulted in a maximum of seven scans/min. Each single scan was split into three different images, each representing about a 200° segment. Scans were obtained at the level of the orbitomeatal line + 5–6 cm, which is the usual level at which an anastomosis is performed; occasionally, a second series of scans was obtained at the level of major extension of an ischemic area. A series of five scans was begun at the start of injection of contrast medium. Sixty ml of contrast material containing a total dose of 21 g iodine was

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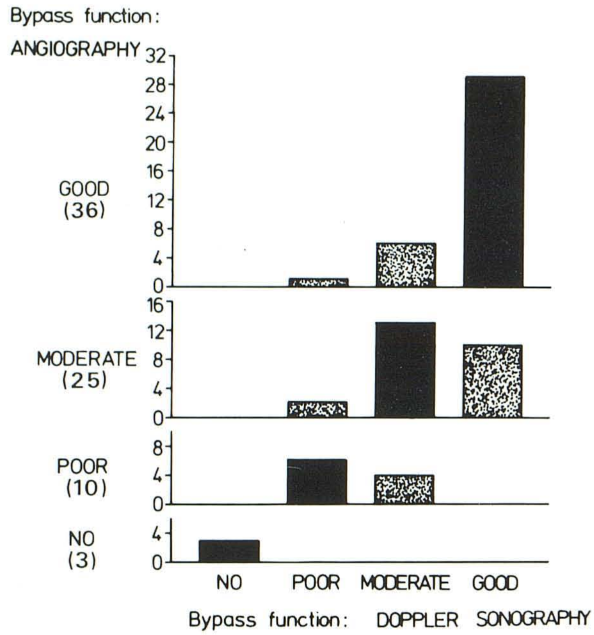


Fig. 1.—Correlation of postoperative angiographic and Doppler sonographic evaluations of EC–IC bypass function in 74 patients. (Numbers in parentheses represent angiographically graded bypasses; shaded areas represent discrepancy between evaluations by Doppler sonography and angiography.)

injected into an antecubital vein within 9 sec. The CT scans obtained at each given time interval from the start of injection were evaluated visually for the time-dependent appearance of contrast enhancement; and for any chosen region of interest, the mean absorption values were calculated and plotted against the time interval, a software function. In a comparison of the pre- and postoperative sequences of scans, bypass function was graded from + to +++.

Results

Doppler Sonography

Doppler sonography always confirmed patency or occlusion of the bypass as demonstrated by angiography. Moreover, a 100% correlation between the Doppler findings and the angiographic criteria for the rating of bypass function was found in the group of patients with good anastomoses. However, there were some discrepancies between the Doppler findings and the angiographic estimate of bypass function in those patients whose bypasses were judged to contribute insignificantly to the intracranial circulation, filling only the recipient cortical artery or even only its distal portion (fig. 1).

Dynamic CT

Visual inspection of pre- and postoperative dynamic CT scans provides an approximate idea of the cerebral circulation patterns. At the level of the brain that was usually examined, the cross section of the sylvian fissure with the branches of the middle cerebral artery and the draining veins showed a maximum of vasculature. However, it was difficult if not impossible to distinguish between arteries and veins on the basis of the CT findings.

Figure 2 shows the application of dynamic CT scans in a typical case, that of a 27-year-old woman who had a minor stroke due to left middle cerebral artery occlusion. Both pre- and postoperative scans show a lower perfusion in the left hemisphere than in the right; however, enhancement values after EC–IC bypass (fig. 2D) demonstrate a better perfusion of the left hemisphere postoperatively than preoperatively. This corresponds with the angiographic demonstration of a well functioning bypass (fig. 2E).

Table 1 presents the results of the postoperative evaluation in the 17 patients in whom all three studies—angiographic, Doppler sonographic, and dynamic CT—were performed.

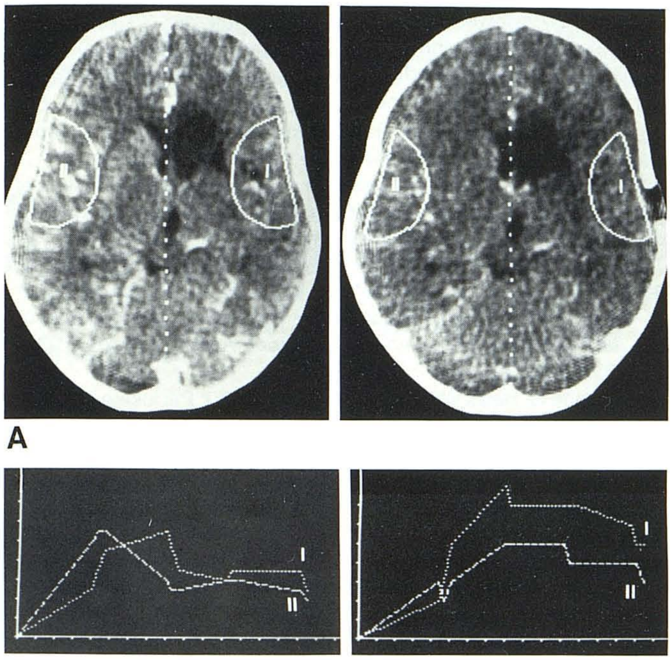
Discussion

Although angiography has long been considered the most reliable method of evaluating EC–IC bypass function, noninvasive methods have gained increasing attention. Doppler sonography has many advantages over other noninvasive examinations: It is a simple and inexpensive technique that can be performed repeatedly and it has proven value in detection of vascular diseases [4]. Our data show that by applying a battery of criteria for evaluating bypass function, it is possible to obtain a close correlation between the data obtained from angiography and from Doppler sonography, respectively, to estimate the degree to which the surgical anastomosis contributes to the intracranial circulation. On a routine clinical basis, it is sufficient to determine whether an EC–IC bypass is functioning well, moderately, or poorly. In patients with internal carotid siphon stenosis, it is also possible, by using Doppler sonography, to detect transition from stenosis to internal carotid artery occlusion. The only category of patients difficult to assess precisely by Doppler sonography is that comprising cases of middle cerebral artery stenosis presenting with another ischemic event. In these patients, the symptoms of recent onset may reflect a variety of lesions that would require a new angiography if surgery is under consideration.

The primary disadvantage of Doppler sonography is that it is limited to the demonstration of extracranial vascular disease. It can only indirectly demonstrate intracranial, hemodynamically significant lesions. For this reason, it is impossible to determine, by Doppler sonography, the extent of intracranial collateral circulation through the circle of Willis and the leptomeningeal collaterals. We therefore looked for another noninvasive method of evaluating the hemispheric perfusion—a method that offered the same advantages as Doppler sonography and that was more easily accessible in a routine clinical setting than, for example, positron emission tomography or xenon-enhanced CT measurements of regional cerebral blood flow.

Dynamic CT has been reported [5–13] to be capable of demonstrating the cerebral perfusion pattern in patients who have suffered an ischemic accident. This claim requires the assumption that, in the case of a bolus administration, the rise in absorption values or CT density is mainly attributable to the passage of intravascular contrast material through the blood [7]. Technical problems that may limit the reliability of this method include the need to: (1) assume an identical extracerebral circulation time when doing repeated studies in the same patient; (2) inject the contrast medium in a standardized manner; (3) start injection of contrast medium and CT imaging, respectively, in a standardized time relation; and (4) select useful regions of interest. In order to limit the influence of these factors on the evaluation of cerebral perfusion in our studies, we determined the perfusion pattern through reference vascular structures such as the superior sagittal sinus and the anterior cerebral artery complex; further, we compared the involved hemisphere with the uninvolved hemisphere, although this tactic proved to be of limited value in the patients with bilaterally symptomatic vascular disease.

The averaging of the absorption values for certain regions of interest includes not only cerebral tissue but also the cerebral



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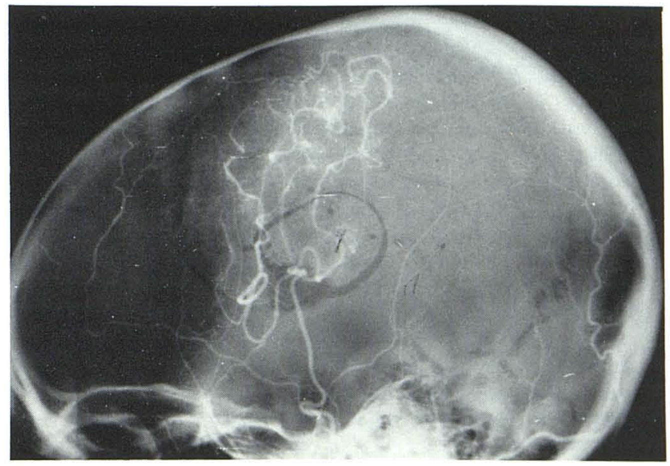

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Fig. 2.—Case 15. 27-year-old woman with minor stroke due to left middle cerebral artery occlusion. **A,** Preoperative dynamic CT scan and **(B)** plot of mean absorption values for two selected regions of interest (outlined in **A**) plotted against time from start of contrast injection. **C,** Dynamic CT scan 5 days after EC–IC bypass surgery and **(D)** postoperative plot of mean absorption values for regions of interest. **E,** Postoperative selective external carotid angiogram. Patent superficial temporal artery–middle cerebral artery anastomosis.

TABLE 1: **Postoperative Evaluation of Extra-/Intracranial Arterial Bypass in 17 Patients**

Case No. (Age, Gender)	Lesion	Evaluation of Bypass Function: Angiography	Doppler Sonography	Dynamic CT
1 (52,M)	ICA occl	++	++	++
2 (50,M)	ICA occl	+++	+++	++
3 (46,M)	ICA occl	++	++	++
4 (46,M)	ICA occl	+	+	+
5 (68,M)	ICA occl	++	++	++
6 (53,M)	ICA occl	++	+++	++
7 (49,M)	ICA occl	++	++	++
8 (58,F)	MCA occl	++	++	++
9 (56,M)	ICA occl	++	++	+
10 (64,M)	ICA occl	+	++	+
11 (68,M)	ICA occl	++	++	++
12 (44,M)	ICA occl (bilat)	++	++	++
		++	++	++
13 (53,M)	ICA occl	+	+	++
14 (54,F)	ICA occl (bilat)	+	+	+
		+	+	+
15 (27,F)	MCA occl	++	++	++
16 (44,F)	MCA occl (bilat)	+	+	++
		+	+	+
17 (49,M)	MCA occl (part)	+	+	+++

Note.—ICA = internal carotid artery; MCA = middle cerebral artery; occl = occlusion; bilat = bilateral; part = partial; + = poor; ++ = moderate; +++ = good.

vasculature, particularly the well demonstrated arteries and veins in the sylvian fissure [9]. It is difficult to examine these cerebral vessels in exactly the same plane on two separate studies, so this may lead to some variations in the perceived cerebral perfusion pattern for these regions [10].

The data presented in table 1 show a good correlation between the findings of angiography, Doppler sonography, and dynamic CT. This is particularly true for the homogeneous group of patients who had internal carotid artery occlusion. Only in one patient (case 17) was there major discrepancy between the estimate of bypass function by Doppler sonography and angiography when compared with the dynamic CT scan. This patient presented with occlusion of the left angular artery. Angiography showed a patent bypass irrigating the territory of the angular artery; Doppler sonography again demonstrated a patent bypass without major increase of flow through the superficial temporal artery. The dynamic CT scan showed a major increase of brain perfusion on postoperative day 7. This may have been the result of local postoperative hyperemia, although we did not observe this phenomenon in other studies.

Eight of the 20 postoperative CT scans were obtained within 7 days after surgery; only two were obtained more than 2 months after surgery. We did not observe any difference in the degree of correlation between angiogram and CT scan estimates of bypass function between the two subgroups of patients who underwent CT within 1 week and later than 1 week after surgery, respectively.

In the group of patients who underwent Doppler sonography, we noted a good correlation between the clinical follow-up assessment and the Doppler sonographic estimate of bypass function on subsequent examinations. Because of our short CT follow-up time, we are not yet able to confirm this finding for dynamic CT studies. Further study is necessary to correlate long-term clinical outcome with late postoperative dynamic CT findings and to better define the role of this method in the management of patients who undergo EC–IC bypass surgery.

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