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Transcranial Color-Coded Doppler Sonography of Intracranial Aneurysms before and after Endovascular Occlusion with Guglielmi Detachable Coils

Bernhard Schuknecht, Jing-Jing Chen, and Anton Valavanis

BACKGROUND AND PURPOSE: Our purpose was to evaluate the ability of transcranial color-coded Doppler sonography (TCCD) to 1) identify Guglielmi detachable coils (GDCs) within intracranial aneurysms, 2) show endovascular aneurysmal occlusion and patency of parent and branch arteries, 3) determine the flow velocities within parent arteries and major branches before and after treatment, and 4) assess persistence of aneurysmal occlusion.

METHODS: The sonographic appearance of GDCs was established experimentally by TCCD (2 to 2.5 MHz), which was then performed in 40 patients with 43 aneurysms occluded by GDCs. The patency of parent arteries and major branches was assessed qualitatively and compared with the immediate posttherapeutic angiographic appearance in every patient. Flow velocities were selectively measured and compared before and after treatment in 21 parent arteries and 24 major branches. Follow-up TCCD studies performed in 26 patients were compared with angiographic (16 cases) and MR angiographic (10 cases) findings for signs of recanalization of the treated aneurysms.

RESULTS: The GDCs were identified experimentally and in the patients as hyperechoic structures of the size and shape, and in the location of, the treated aneurysm in 41 of 43 cases. TCCD in accordance with angiography showed a lack of flow in 42 aneurysms and the presence of flow signal in one large aneurysm. Patency of the parent artery was shown in 40 aneurysms and in all branches. Follow-up TCCD showed the coils unchanged in 23 of 26 cases. In three large aneurysms, TCCD indicated recanalization and reappearance of a flow signal separate from the parent artery.

CONCLUSION: TCCD is a reliable, noninvasive means to assess parent artery and major branch patency and to reveal a lack of hemodynamic compromise in the vicinity of aneurysms after endovascular therapy. On follow-up examinations, TCCD was able to detect signs of aneurysmal recanalization.

Since the presentation of the first clinical results (1, 2), endovascular treatment of intracranial saccular aneurysms by electrolytically detachable platinum coils has evolved as an accepted alternative to surgical clipping. The interventional approach has gained considerable attention in the management of aneurysms of the posterior circulation (3–5), of multiple aneurysms (6), and of aneurysms in patients considered

poor surgical candidates for, or unwilling to undergo, surgery (3, 7). A prerequisite for endovascular obliteration is a favorable configuration of the aneurysm with a definable and, preferably, small ostium (1, 8).

The initial degree of aneurysmal occlusion can be seen well on immediate postembolization angiograms (9). However, to assess the intermediate- and long-term results of endovascular treatment, regular follow-up angiography is advocated (1, 10).

With transcranial color-coded Doppler sonography (TCCD), however, a noninvasive means is available that allows one to assess flow velocity within and adjacent to intracranial aneurysms (11–13) and to monitor the periprocedural effects of endovascular electrothrombosis (14). The aim of our study was to assess the ability of TCCD to depict Guglielmi detachable coils (GDCs; Target Therapeutics, Fremont,

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CA) within intracranial saccular aneurysms, to evaluate the effect of endovascular therapy both qualitatively and quantitatively within the parent artery and major branches close to the aneurysm, and to provide clues as to aneurysmal recanalization after endovascular therapy.

Methods

Experimental Determination of the TCCD Appearance of GDCs

The sonographic appearance of the coils on transcranial B-mode images was determined in an initial experiment preceding the patient examinations. A human cadaveric head was used with the skull opened in an axial plane at the level of the tip of the frontal sinus. The skin and temporalis muscle remained attached to the squama temporalis for the transtemporal sonographic approach used. The brain had been removed and was replaced by soft tissue that on transcranial B-mode imaging proved to have equivalent echogenicity to brain. A liquid solution was used to remove air and to simulate CSF. Three GDCs were introduced consecutively into a small, fluid-filled space within the substitute brain and detached at a depth of 6 to 7 cm, simulating the location of the internal carotid artery or basilar artery bifurcation. Two soft GDCs were used with a helical diameter of 3 mm and lengths of 4 cm and 8 cm, respectively; one GDC was used with a helical diameter of 8 mm and a length of 20 cm. The appearance of the coils was assessed on B-mode imaging with the same parameters as those used for the patient examinations.

Initial Pre- and Postembolization Patient Examinations

Over a period of 3 years, 40 patients (23 women, 17 men; age range, 17 to 72 years; mean age, 47 years) with 43 intracranial saccular aneurysms were examined by TCCD. The subjects were selected from a series of consecutive patients with a total of 90 aneurysms who underwent endovascular therapy performed by the senior author. Twenty-six patients were included on the basis of a previous TCCD examination conducted prior to treatment. The other 14 patients were referred randomly by the senior author early in our series, and had no preceding TCCD examination.

TCCD Examination

TCCD was performed 1 to 2 days before and 1 to 5 days after GDC treatment; a 2.0- or 2.5-MHz sector probe was used with an aperture size of 19×14 mm (Acuson, Mountain View, CA). High temporal and spatial resolution was selected by using a low wall filter. Multivariate motion discrimination processing was adjusted to detect the lowest velocities and signal levels. Power Doppler was additionally applied to increase sensitivity to slow flow and to flow components rectangular to the probe. Images were obtained in axial and coronal planes. In standard color Doppler imaging, the color blue indicated flow toward the probe and red revealed flow directed away from the probe. The color-flow image was acquired with a standard mean velocity sensitivity (± 30 cm/s) and with a continuously decreasing pulse repetition frequency in order to increase sensitivity to slow flow down to 2 cm/s. The color-flow images were magnified by a factor of three for detailed real-time analysis of flow in the parent artery and major branches adjacent to the treated aneurysm.

The TCCD examinations were interpreted without knowledge of the results of embolization except for the location, size, and configuration of the treated aneurysm. The latter was judged on the basis of a preceding TCCD examination in 26 patients and on the basis of preembolization angiography and 3D CT angiography (Siemens Plus 4, Erlangen, Germany), which were performed in all patients.

The results of endovascular therapy were withheld in order to prevent any bias exerted by knowledge of the postembolization angiographic findings with respect to the degree of aneurysmal occlusion and the presence of a potential compromise of the parent artery and/or adjacent branches. For this reason and in order not to interfere with the treatment procedure, TCCD was not performed during delivery of the coils.

TCCD criteria indicating complete aneurysmal occlusion included hyperechoic signal in the location of and of the size and shape of the treated aneurysm and a lack of motion of the GDC mesh during real-time B-mode examination. Criteria that at color Doppler imaging indicated aneurysmal occlusion included a lack of intraaneurysmal flow with the lowest velocity encoding available and reconstitution of a unidirectional "flow" contour with a normal-diameter vessel at the previous ostium.

The TCCD examinations were subsequently compared with the immediate postembolization angiograms in 40 patients with respect to aneurysmal occlusion and patency of parent arteries and major branches arising close to the aneurysm. In four patients with an insufficient bone window, an echo-enhancing agent (Levovist, 300–400 mg/mL, Schering, Germany) was administered intravenously.

In 26 GDC-treated aneurysms, a follow-up TCCD examination was performed within 6 to 20 months (mean, 11 months). The color Doppler images were analyzed with respect to signs of recanalization, including coil displacement, compared with the first examination, the presence of pulse-synchronous coil movement during real-time analysis, and flow in between or adjacent to the GDCs separate from the parent artery or branches. The findings were compared with the results of follow-up angiography in 16 patients and MR angiography (phase-contrast and time-of flight angiography) in 10 cases. TCCD and follow-up angiography or MR angiography were obtained on the same day in all patients.

TCCD Data Analysis

In 20 patients with 21 aneurysms (including 21 parent arteries and 24 branches), flow velocity could be compared before and after GDC treatment. Based on the magnified color Doppler image, an angle-corrected sample volume was selectively positioned in the parent artery and at the origin of the branches. Sample volume gate size was 3 to 4 mm within the parent arteries and 2 to 3 mm within the branches. The Doppler spectra obtained were assessed with respect to the time-averaged maximal velocity and the peak-systolic and end-diastolic velocity. For further statistical analysis the aforementioned data were corrected for unrelated velocity changes between the two studies: the velocity value in the parent artery and branches was divided by the velocity in an artery topographically unrelated to the aneurysm (reference artery). This ratio was correlated before and after endovascular treatment. The data were statistically analyzed by paired *t*-test.

Angiography

Angiographic criteria for complete occlusion included the inability to place any additional small coils after tightly packing the aneurysmal sac and a subsequent lack of opacification of the aneurysmal ostium and sac. A small remnant was defined as minimal contrast opacification at the site of the previous ostium in an aneurysm considered more than 90% occluded.

Endovascular treatment was performed within 10 days after rupture in 22 aneurysms and between 14 days and 6 months in six aneurysms; eight aneurysms were detected as a result of a space-occupying effect, and seven aneurysms were incidental findings.

Results

Sonographic Appearance and Detectability of GDCs

In the three experiments performed on a cadaveric skull to evaluate the sonographic characteristics of platinum coils, a hyperechoic signal was detected after introduction of the GDC into the plane of insonation (Fig 1). The signal disappeared when the

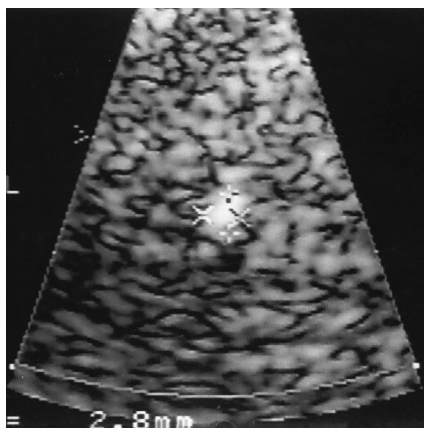


FIG 1. Axial B-mode image (2.5 MHz, transtemporal view) from experimental study after introduction of 3 × 8-mm GDC coil. The coil is characterized by a focal area of increased echogenicity without acoustic shadowing. The size of the hyperechoic area corresponds closely to the size of the circular memory of the coil.

coil was removed. After the GDC had been detached, the diameter of the area of increased echogenicity was measured. The diameter of hyperechogenicity corresponded to the circular memory of the largest coil; that is, 2.8 mm and 3.2 mm for the two coils with a 3 mm diameter, and 8.3 mm for the coil with an 8-mm diameter.

In the 43 patients examined by TCCD after endovascular therapy, the B-mode image showed that the location and size of the area of increased echogenicity, as determined by angiography and 3D CT angiography, respectively, corresponded to the location of the previous aneurysm in 41 (95%) of the occluded aneurysms; in two cavernous carotid aneurysms (5%), the proximity of the coils to adjacent hyperechoic bone prevented recognition of the GDCs (see Tables 1 and 2).

Owing to tight packing of coils within the aneurysm, the hyperechoic signal was identical in all aneurysms (Fig 2A and B). The only exception was one loosely packed aneurysm, which appeared as an area of intermediately increased echogenicity (Fig 3A and B). The echogenicity in this case increased markedly when coil compaction occurred during recanalization (Fig 3C).

Aneurysmal Occlusion and Recanalization

The immediate postembolization TCCD examination revealed a lack of flow in the location of the

TABLE 1: Location and Size of 43 Aneurysms

Location/ Size (mm)	Internal Carotid Artery			Posterior Communicating Artery	Anterior Communicating Artery	Middle Cerebral Artery	Basilar Trunk	Vertebral Basilar Junction	Posterior Inferior Cerebellar Artery
	Pars Cavernosa	Ophthalmic	Bifurcation						
<6	...	...	1	1	2	3	4	...	2
6–12	...	1	...	1	3	...	5 + 2*	1	...
12–25	5	3	1	1	1	1	1	...	...
>25	...	1	...	...	...	...	3	...	...
	5	5	2	3	6	4	15	1	2

* Basilar trunk.

TABLE 2: Comparison of Findings Before and After Treatment and at Follow-up Transcranial Color-coded Doppler Sonography (TCDD), Angiography, and MR Angiography

	No. of Aneurysms	No. with Intraaneurysmal Flow	No. with Parent Artery Patency	No. with Branch Patency*	GDC Presence	GDC Displacement	GDC Movement
Before treatment							
Angiography	43	43	43	35	...	...	...
TCCD	27	25†	27	22	...	...	...
After treatment							
Angiography	43	1	40*	35	43	...	...
TCCD	43	1	40*	35	41	...	1
Follow-up							
Angiography	16	3	16	14	16	3	...
MR angiography	10	...	10	8	10	...	...
TCCD	26	3	26	22	26	3	3

* Not applicable in five aneurysms of the internal carotid artery (pars cavernosa), in two aneurysms of the basilar trunk, and in one aneurysm of the vertebral basilar junction.

† Two aneurysms were not identified.

* Three aneurysms had additional balloon occlusion of the parent artery.

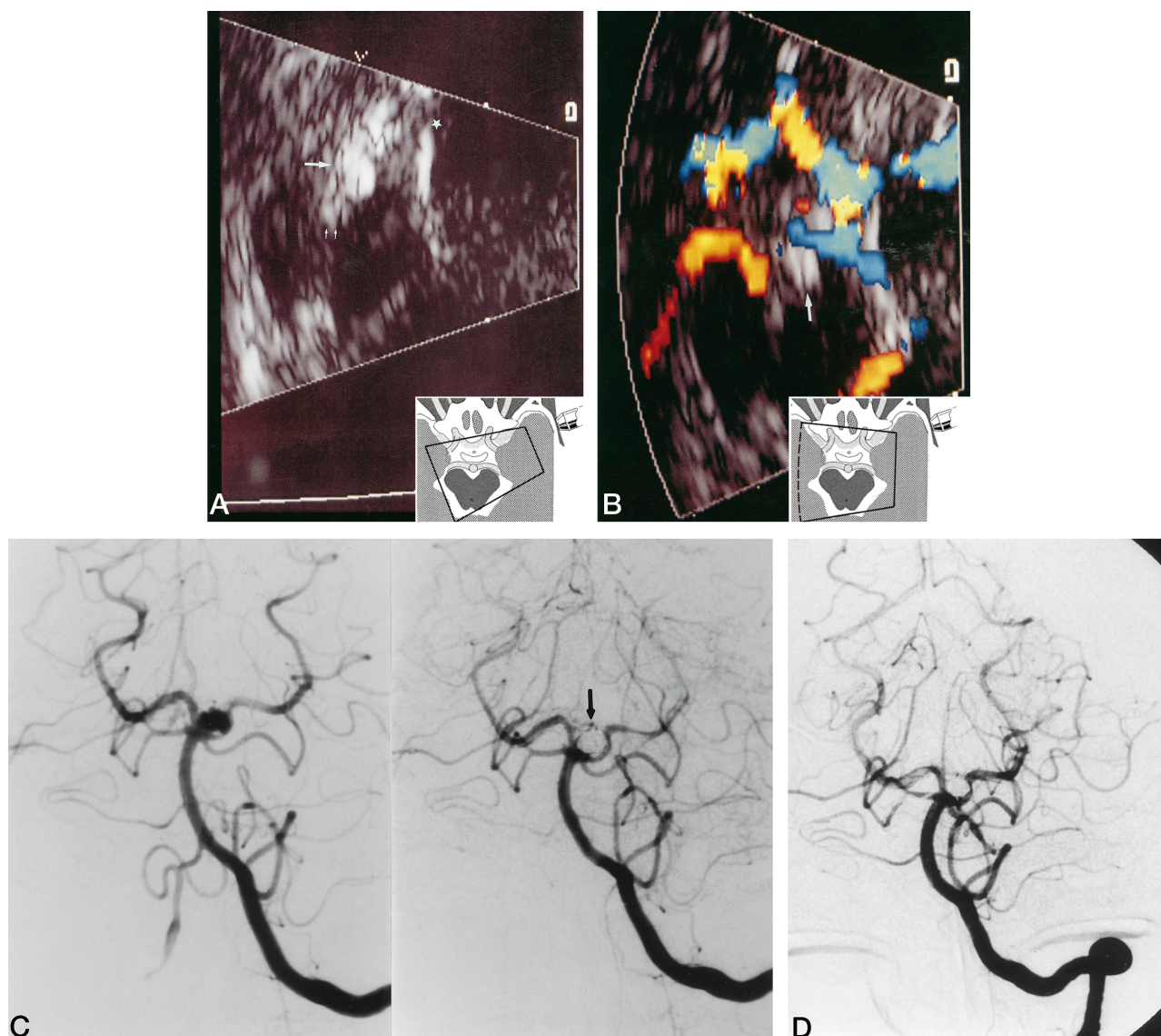


FIG 2. 50-year-old patient with a ruptured basilar tip aneurysm.

A, Transtemporal axial B-mode image depicts normal hypoechoic appearance of mesencephalon and typical, slightly hyperechoic interpeduncular cistern (*small arrows*). Note linear hyperechoic left petroclinoid ligament (*star*). Hyperechoic GDCs (*large arrow*) point toward the left cerebral peduncle. The echogenicity is high as compared with Figure 1 owing to tight GDC packing of the aneurysm.

B, Corresponding color-flow image shows the circle of Willis and the hyperechoic tightly packed coils (*arrow*) directed away from the left P1 segment. The proximal P1 and distal P2 segments are partly out of plane owing to an ascending and descending course, respectively, depicted in C.

C, Digital subtraction angiograms, left vertebral injection, before (*left*) and after (*right*) endovascular treatment with GDC coils show completely occluded basilar tip aneurysm with minimal widening at the ostium to preserve the origin of a thalamic perforator (*arrow*) and the left P1 segment.

D, Follow-up angiogram after 9 months shows persistent aneurysmal occlusion.

previous aneurysm in 42 of 43 aneurysms (Table 2). In four aneurysms, slight residual flow was recognized on the immediate posttreatment angiogram. Therefore, the rate of completely occluded aneurysms was 89% (35/39) in this series when giant aneurysms were not taken into consideration. In agreement with angiographic results, the color-flow image revealed a lack of flow within the aneurysmal sac in all but one palliatively treated cavernous carotid aneurysm. In the latter case, flow signal was present between the loops of the coils (Fig 3A–C).

When 26 aneurysms were reexamined 6 to 20 months (mean, 12 months) after endovascular treatment, displacement and compaction of coils was recognized in three cases (11.5%). Reappearance of flow signal adjacent to the coils was an additional sonographic feature, as was pulse-synchronous movement of the coils. In two instances, large bifurcation-type (ophthalmic and basilar tip) aneurysms had been present; another patient had had a cavernous carotid aneurysm. Recanalization was shown by TCCD and confirmed by subsequent angiography in all three

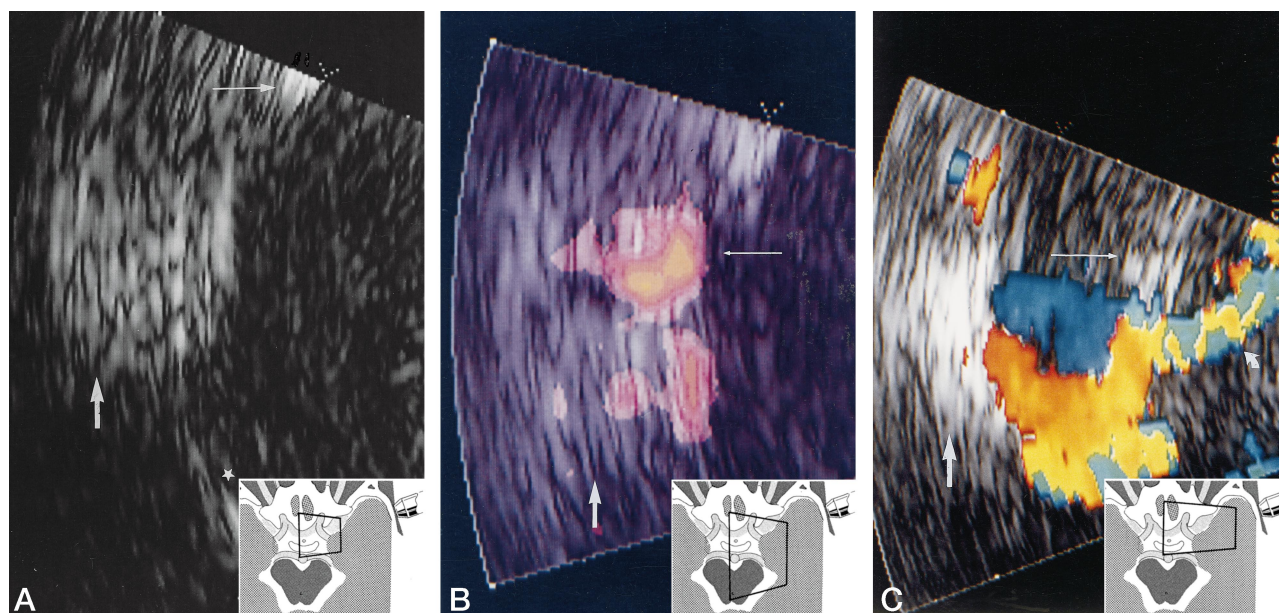


FIG 3. A, Transtemporal axial B-mode image reveals area of intermediately increased echogenicity (*wide arrow*) posteromedial to anterior clinoid process (*thin arrow*), anterior to petroclinoid ligament (*star*). The circular hyperechoic area corresponds to intentionally loosely packed GDC coils within large cavernous carotid aneurysm.

B, The equivalent axial power Doppler image depicts flow among coils (*wide arrow*) most prominent in anterolateral portion of the aneurysm (*thin arrow*).

C, Corresponding axial echo-enhanced (Levovist) color-flow image repeated after 14 months shows major recanalization due to medial compaction of the now considerably hyperechoic coils (*wide arrow*). Bidirectional flow, typical for a nonoccluded aneurysm, is seen in the lateral recanalized portion located posteromedial to anterior clinoid process (*thin arrow*) and medial to M1 segment of middle cerebral artery (*curved arrow*).

cases (Table 2). Retreatment was successful in two patients. In 23 cases, persistent occlusion was shown by TCCD and was confirmed by angiography in 13 instances. In an additional 10 cases, TCCD was compared with MR angiography (Table 2). In these cases, no evidence of recanalization was present either on the collapsed MR angiographic image or on the individual sections.

Hemodynamics in Parent Arteries and Major Branches

In accordance with angiographic findings, color Doppler imaging confirmed patency of the parent artery in 40 of 43 aneurysms (Table 2). In the other three aneurysms, balloon occlusion of the parent artery had been performed in addition to GDC occlusion. In these cases, angiography and TCCD showed parent artery and aneurysmal occlusion and the presence of collateral flow. Patency of branches adjacent to the occluded aneurysms was delineated in every case by color B-mode imaging and angiography (Figs 2 and 4).

In 21 parent arteries, a statistical analysis of the flow velocity before and after endovascular therapy revealed no significant difference among the peak-systolic ($P = .96$), end-diastolic ($P = .90$), and time-averaged maximal flow ($P = .90$) velocities (Fig 5A). Likewise, in 24 branches, the TCCD velocity recordings showed a high correlation when the pre- and

posttherapeutic data were compared for the maximal systolic ($P = .90$), end-diastolic ($P = .87$), and time-averaged maximal flow ($P = .83$) velocities (Fig 5B).

As expected, the flow velocity was found to differ significantly between the basilar artery and supratentorial arteries ($P = .00099$). A tendency for a greater change in flow velocity was found in patients with recent subarachnoid hemorrhage as compared with patients who had no hemorrhage (time-averaged maximal velocity, $P = .77$ versus $.98$).

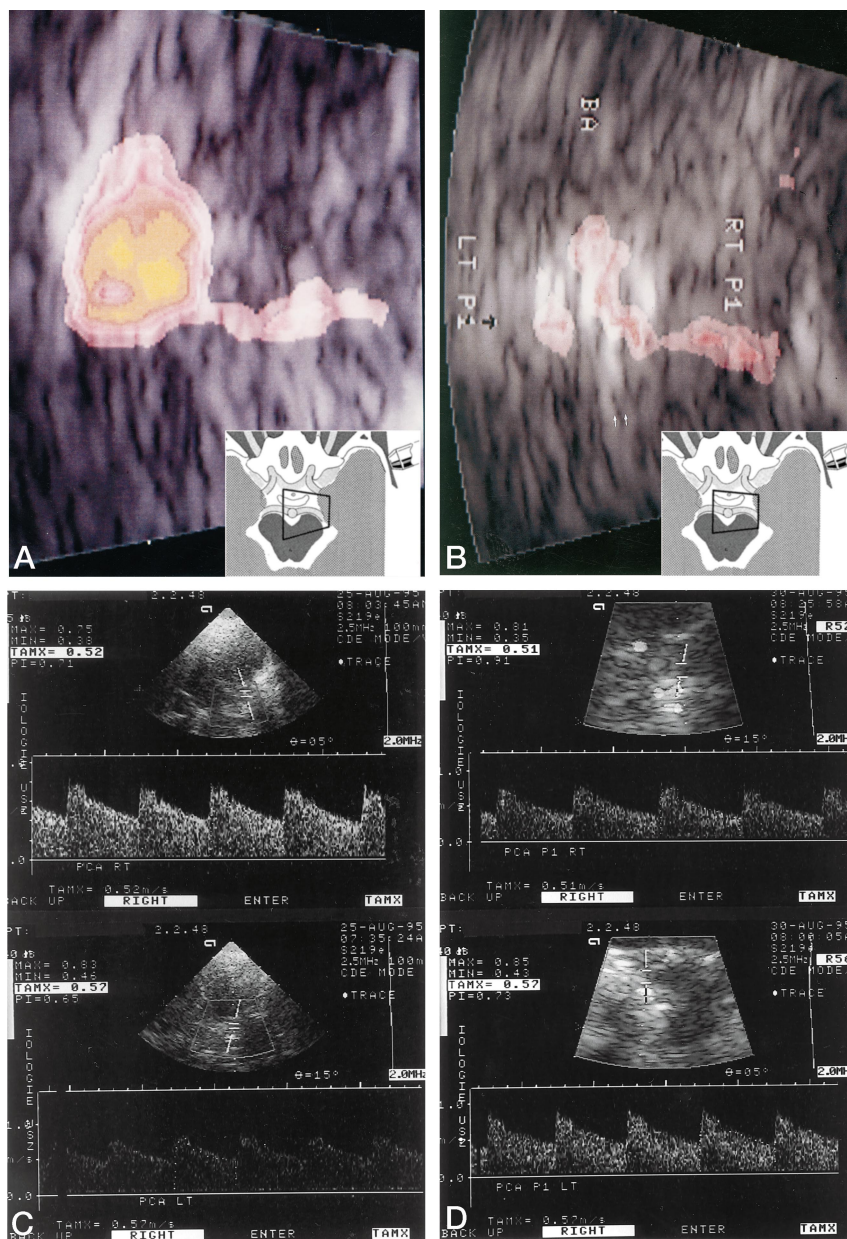
Discussion

Cerebral angiography is advocated as the primary imaging technique for monitoring the effects of endovascular electrothrombosis of intracranial aneurysms with GDCs (1, 2, 9, 15). This holds particularly true when the immediate postembolization angiogram reveals a remnant at the base (6), which is frequent in aneurysms with a large ostium (8, 9). While large and giant aneurysms with a wide ostium present specific problems irrespective of the type of treatment administered, aneurysms with a small base have been totally occluded by endovascular electrothrombosis in 71% (9), 85% (10), and 85% (8) of studies reported in the literature. In our patients, angiography showed complete occlusion in 34 (89%) of 39 small, medium, and large aneurysms. In the remaining four aneurysms, a small remnant at the

FIG 4. A, Transtemporal axial power color Doppler image of anteriorly directed basilar tip aneurysm with the adjacent P1 segment of the right posterior cerebral artery.

B, Close-up of A after endovascular treatment: hyperechoic GDCs are in the position of, and of the size of, the obliterated aneurysm. Patent right P1 segment (short left P1 portion) is now visible.

C and D, Comparison of flow velocity (time-averaged maximal velocity) before (C) and 4 days after (D) endovascular occlusion depicts noncompromised flow in the right (top) and left (bottom) P1 segments.



ostium was recognized on the immediate posttherapeutic angiogram.

A more sophisticated approach in the follow-up regimen would include differentiating totally occluded aneurysms from those that are incompletely eliminated at the end of endovascular therapy. Our objective was to either obviate repeat angiography in certain patients or to direct angiography more specifically to those patients whose aneurysms are thought to have recanalized.

TCCD has evolved as an increasingly accepted technique to noninvasively assess the intracranial basal arteries (16, 17). However, the use of TCCD to monitor the effects and results of intracranial interventional procedures is still uncommon (14). This is despite the fact that TCCD has proved able to identify intracranial aneurysms in 76% (17) to 85% (18) of cases.

Technical refinements based on the amplitude or signal intensity of moving targets allow us to extend the displayed signal range into the "noise floor"; thus, the power Doppler technique increases sensitivity to low-level signal or very slow flow that otherwise would be disturbed by random noise. With this technique, in accordance with Wardlaw et al (14), we noted improved identification of branches adjacent to the aneurysm. Decreased dependence of the angle of insonation and the ability to display low flow in random directions favor application of power Doppler over conventional Doppler imaging to detect residual flow within the aneurysm after electrothrombosis. The theoretically lower threshold of power-based Doppler imaging still did not provide a signal correlate in those cases that displayed very small contrast residue at the site of the previous ostium on the immediate posttreatment angiogram in four of our

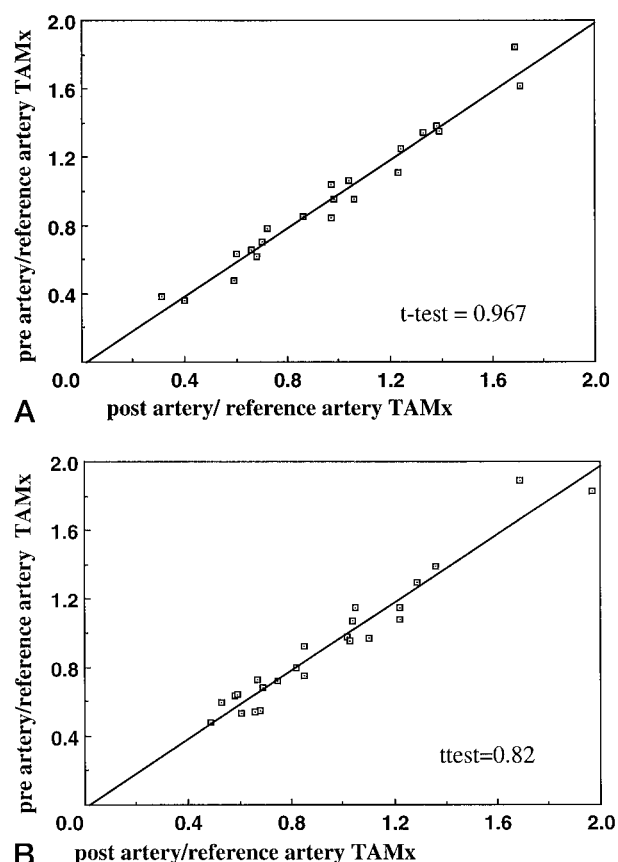


Fig 5. A and B, Correlation of ratio of parent artery to reference artery in 21 parent arteries (A) and ratio of major branch to reference artery in 24 major branches (B) before and after embolization. The rise of the graph is close to 1 in each case, indicating strong correlation and therefore lack of compromise of flow velocity within parent artery and in major branches close to the aneurysm before and after GDC treatment. (TAMx indicates time-averaged maximal velocity.)

patients. This discrepancy is thought to be due to the superior spatial resolution of angiography as compared with TCCD. However, TCCD was able to show recanalization (subsequently proved by angiography) in two of these aneurysms and a lack of recanalization in the other two.

Residual flow between the coils after palliative endovascular therapy with intentionally loose GDC packing was observed by angiography and TCCD in only one aneurysm (Fig 3B). Residual flow within the aneurysm at the end of the endovascular procedure was reported by Wardlaw et al (14) in two of seven aneurysms examined by TCCD. Follow-up examinations in our series detected flow within the partly recanalized portion of another two aneurysms. Residual flow at the inflow rather than outflow tract may correlate with an increased risk of recanalization. TCCD has been shown to be able to noninvasively differentiate the inflow from the outflow tract in lateral-type aneurysms (19).

On B-mode (gray-scale) images in our experimental study, GDCs were recognized as hyperechoic areas whose diameters closely corresponded to the cir-

cular memory of the largest GDC. Physically, the percentage of ultrasound energy transmitted or reflected depends on the propagation speed and the densities of the different media. A reflection of 82% was thus calculated on the basis of the specific density of platinum at 21.4 g/cm³ and of soft tissue at 1.06 g/cm³ (20). The high signal thus reflects the difference of impedance between platinum and soft tissue and therefore is not specific to GDCs. A similar appearance was noted for aneurysmal clips.

Despite the fact that the intensity of the ultrasound beam returning to the Doppler transducer is mainly determined by reflection, scattering is also relevant. This is due to the small diameter of the individual coil loops (GDC 10 = 0.244 to 0.256 mm; GDC 18 = 0.346 to 0.385 mm) compared with the wavelength of the incidental ultrasound beam, which is 0.77 mm for 2 MHz. On a physical basis, delineation of residual flow between the coils is possible, and was confirmed in one case (Fig 3) early after endovascular treatment, and in an additional two patients after partial aneurysmal recanalization. Acoustic shadowing has not been observed, despite tight packing of the GDCs (14, 21). The color-coded Doppler signal, therefore, was not compromised and allowed us to map the parent vessel segment at the ostium of the occluded aneurysm and at the origin of adjacent branches (Fig 4). On digital subtraction angiography, however, the presence of densely packed coils may occasionally preclude adequate visualization of the adjacent parent artery or proximal branches.

Visualization of flow signal by TCCD enables recognition of patency of the parent artery and branches adjacent to the aneurysm. Unintentional parent artery occlusion, which has recently been reported in 12 of 403 patients treated with GDCs (9), was therefore ruled out by TCCD in our series. Untoward cerebral clot embolization or coil dislocations did not occur. A single complication that arose during the treatment procedure was the rupture of an aneurysm of the posterior inferior cerebellar artery, which was treated in the acute phase after subarachnoid hemorrhage. The bleeding stopped without clinical sequelae once delivery of the coils was continued.

The color-flow image provides the basis for a selective real-time acquisition of Doppler spectra and thus permits the precise quantification of flow velocity in a specific location. A comparison of the pre- and postembolization flow velocities in the parent artery and in major branches (Fig 5A and B) showed a lack of hemodynamic compromise in the vicinity of the GDC-occluded aneurysms in this series. Comparison of flow velocities was facilitated in four patients by the availability of an intravenous echo-enhancing agent used as a contrast medium, which substantially increased the signal in the presence of an inadequate temporal bone window.

Although Wardlaw et al (14) used TCCD during delivery of the coils, our patients were examined before and after embolization to prevent interference with the procedure. Periprocedural examination also was avoided so that TCCD and interpretation of the

results of endovascular therapy could proceed in a blinded fashion.

Continuing refinements in Doppler technology, such as power Doppler and the availability of echo-enhancing agents as contrast media, have facilitated the application of TCCD; however, the greatest drawback of Doppler sonography has been the dependence on operator capability. Color Doppler and power Doppler imaging represent major advances in decreasing operator dependence. Still, the images provided reflect the mean frequency shift and signal intensity rather than a true picture of vessel morphology. Color Doppler images depict velocity, flow direction, and turbulence and, therefore, are conceptually different from cerebral angiograms. This difference also applies to the plane of insonation: even though TCCD is applied in axial and coronal planes, additional inadvertent rotation of the ultrasound probe occasionally occurs, impairing reproducibility of the imaging plane.

MR angiography has been suggested as a noninvasive alternative to cerebral angiography (4). MR angiography was used in 10 of our patients as the sole follow-up investigation apart from TCCD. The presence of GDCs was indicated by a small semilunar high-signal artifact on both T1- and T2-weighted images adjacent to an area of hypointensity. The latter corresponded to the hyperechoic signal seen by TCCD. Despite the fact that MR angiography is less dependent on the experience of the investigator as compared with TCCD, interpretation of MR angiograms may be impeded by susceptibility artifacts emerging from the coil mesh. The use of shorter repetition times, however, appears to significantly reduce this effect (22). In all our patients and in eight patients recently examined by Hartman et al (23), the artifact caused by the magnetic susceptibility effect was considered minimal with respect to restricting evaluation of the vicinity of the coils.

For follow-up evaluation of intracranial aneurysms after endovascular electrothrombosis, cerebral angiography is considered the standard of reference. However, obscuration of small amounts of contrast-laden blood by the densely packed GDCs may make it difficult for the angiographic image intensifier to detect residual flow (24). The precision with which angiography reveals complete occlusion has been further questioned by an experimental study: after endovascular occlusion of bifurcation aneurysms in chinchilla rabbits, histopathologic examination revealed "open spaces between the coil loops" even in those cases that were thought, by angiographic criteria, to be completely occluded (25). This description, however, does not conform to our observations or to those in a report by Mawad et al (26), who studied angiography-proved occluded aneurysms in six mongrel dogs and found the aneurysmal neck to be completely covered by membranous tissue. These experimental observations were confirmed in a clinical study by postmortem microscopic examination of a patient 4 weeks after GDC occlusion of a basilar tip

aneurysm that revealed the aneurysm to be isolated from the parent artery by a thin layer of fibrin (27).

Conclusion

TCCD proved to be a reliable means of identifying GDCs in the position of a previous aneurysm and of revealing lack of hemodynamic compromise of the parent artery and adjacent branches by the GDCs. TCCD provided signs of early or delayed aneurysmal recanalization, and may therefore be considered useful as a noninvasive means to monitor patients after endovascular treatment of intracranial aneurysms and to specify the necessity of additional follow-up angiography.

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