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Intraaneurysmal Flow: Evaluation with Doppler Guidewires

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Summary: Flow dynamics in cerebral aneurysms were studied with the use of Doppler guidewires in two patients. In both cases it was possible to reach the aneurysmal sac and to assess intraaneurysmal flow. Torquability and flexibility of the new Doppler guidewires permitted continuous assessment of flow velocity and flow pattern at the dome as well as in the neck area. Flow velocities were higher at the neck than within the aneurysmal sac (88 cm/s > 28 cm/s). Because of the limited area of interrogation (sample volume, 5 mm) it was not possible to investigate the complete intraaneurysmal space.

Index terms: Aneurysm, hemodynamics; Interventional instruments, guidewires; Ultrasound, Doppler

Although the use of Doppler guidewires is well established for coronary and peripheral arteries (1, 2), the clinical application of miniaturized Doppler probes in neuroradiology has been described only in a limited number of studies (Benndorf G, Podrabsky P, Wellnhofer E, et al, "Measurement of Blood Flow Velocity by Doppler-tipped Guidewires in Patients with Arteriovenous Malformations and Fistulas," In: Takahashi M, Korogi Y, Mosley I, eds, *Proceedings of the XVth Symposium Neuroradiologicum*, New York, NY: Springer; 1995:489–491). Experimental validation for potential neurologic endovascular applications was done by Chaloupka (3).

In studies of pathophysiology in growth, rupture, and bleeding of cerebral aneurysms, increasing attention has been focused on hemodynamic parameters. In vivo assessment of flow dynamics in such aneurysms is difficult because adequate techniques for sampling quantitative data are lacking. The purpose of this study was to evaluate flow parameters in cerebral aneurysms by means of direct intraluminal measurements made with a Doppler guidewire. Our interest was in determining whether the Doppler guidewire can be used safely during neurointerventional procedures to provide additional functional information on hemodynamics in cerebral aneurysms.

Materials and Methods

In two patients, superselective injection into the aneurysmal sac was performed preoperatively after four-vessel angiography to delineate the relationship between the parent vessel and the neck of the aneurysm. One patient was a 37-year-old woman with a giant (2.5 cm) supraophthalmic aneurysm; the other was a 73-year-old man with a giant (>3 cm), partially thrombosed aneurysm of the right supraclinoid portion of the internal carotid artery (ICA).

The Doppler guidewire used in these cases has a floppy, radiopaque tip (3 cm) into which a miniaturized Doppler probe (15 MHz) is integrated (Smart Wire, Cardiometrics, Mountain View, Calif). Its flexibility is similar to that of other microguidewires, and therefore it can be used in combination with common microcatheters, such as the Tracker-18 (Fig 1). The Doppler probe emits a 28° degree ultrasound beam with a sample volume of 5 mm, located 5 mm distal to the tip. The Doppler signal is analyzed by a device (Smart Map, Cardiometrics) that calculates real-time spectra by using on-line fast Fourier transformation (about 100/s). Instantaneous peak velocity (IPV) is calculated from each spectrum. IPV is comparatively insensitive to artifacts and correlates well with mean velocity. A scrolling gray-scale display permits simultaneous documentation of spectra IPV-tracking, and electrocardiographic measurements. Several hemodynamic parameters (average peak velocity [two cardiac cycles], maximum peak velocity [two cardiac cycles], and pulsatility index [$IPV_{max} - IPV_{mean}$/average peak velocity]) derived from IPV measurements are available. All measurements can be documented on printouts or videotapes.

A Tracker-18 catheter (Fast Tracker, Target Therapeutics, Fremont, Calif) was used for superselective catheterization with road-mapping techniques. After superselective intraaneurysmal injection of 1 to 2 mL of contrast agent, a 0.014-in Smart Wire was introduced into the

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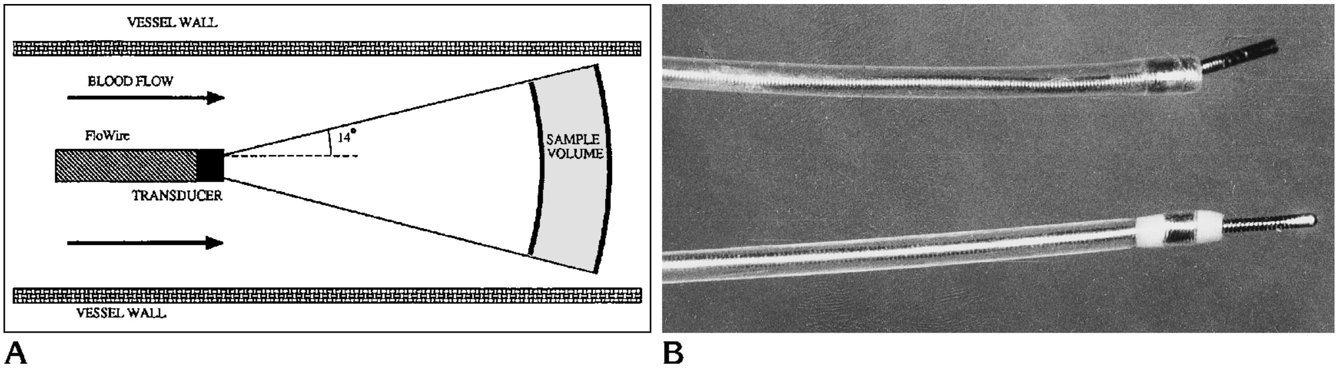

Fig 1. *A*, Schematic drawing of the Smart Wire, a guidewire with an integrated Doppler probe.

B, Photograph of two microwires, both of which can be introduced into a Tracker-18 catheter. *Above*, the 0.014-in Smart Wire with a tip-mounted transducer (J-curved tip); *below*, the 0.014-in Dasher (Target Therapeutics), a commonly used microguidewire for intracranial superselective catheterization.

aneurysm (Fig 2C) and the velocity was measured. During this procedure, the microcatheter and the Doppler guidewire were gradually removed from the wall of the dome to the neck of the aneurysm. Finally, flow in the parent vessel proximal to the neck was measured. Conventional criteria for measuring turbulent flow patterns cannot be applied in this setting, because the spectra only represent the sample volume, generally an oblique section of the flow profile.

We assumed disturbed flow if the following criteria were found: spectral broadening; no sharp tracking line of the IPV due to merging of the signal with noise; and isotropic, intense phenomena of low velocity around the baseline, probably representing small eddies.

Results

Case 1

A 37-year-old woman with slight chronic headaches was referred to our hospital. The CT examination suggested a large intracranial aneurysm. Digital substraction angiography of the right ICA showed a large aneurysm at the distal intracranial ICA bifurcation (Fig 2A). The dome was directed cranially and laterally, displacing the M1 segment caudally. The exact size of the aneurysmal neck and its relationship to the distal ICA as well as to the M1 and A1 segments were not apparent, so preoperative superselective angiography was performed to provide this information to the neurosurgeons. An intraaneurysmal injection (Fig 2B) clearly revealed the size of the aneurysmal neck and the locations of inflow and outflow.

Flow measurement performed under roadmapping guidance (Fig 2C) using the Doppler guidewire provided the following (Fig 2D–F) information. Beginning near the wall of the dome we found a sharp systolic peak and relatively low value of maximum systolic velocity (28 cm/s). Diastolic flow velocity was only 10 cm/s at this spot, and the pulsatility index was high (2.5). At the area of the aneurysmal neck we found a significant increase in peak velocities (maximum, 88 cm/s; average, 59 cm/s) and a decrease in the pulsatility index to 0.9. Flow velocities outside the aneurysmal sac in the parent vessel were generally lower than in the neck area. The pulsatility index was clearly higher near the dome than at the neck or in the parent vessel. On the basis of the velocity spectra, the flow pattern seemed slightly disturbed, especially at the dome.

Case 2

A 72-year-old man came to our hospital with slight visual problems. CT scans showed a contrast-enhancing mass in the right parasellar region. Digital substraction angiography confirmed a giant, partially thrombosed aneurysm of the supraclinoid portion of the right ICA. The dome was directed cranially, with a mass effect displacing the M1 segment. The location of inflow and the correct size of the aneurysmal neck were not sufficiently visible, and the neurosurgeons asked for superselective intraaneurysmal injection. Catheterization of the aneurysmal sac and careful injection of contrast medium into the parent vessel directly at the origin of the neck enabled us to define the relationship between the aneurysmal neck and the lumen of the parent artery. Velocity assessed in the mean direction of flow as seen in the superselective injection was directed cranially against the top of the dome. It showed a sharp systolic peak

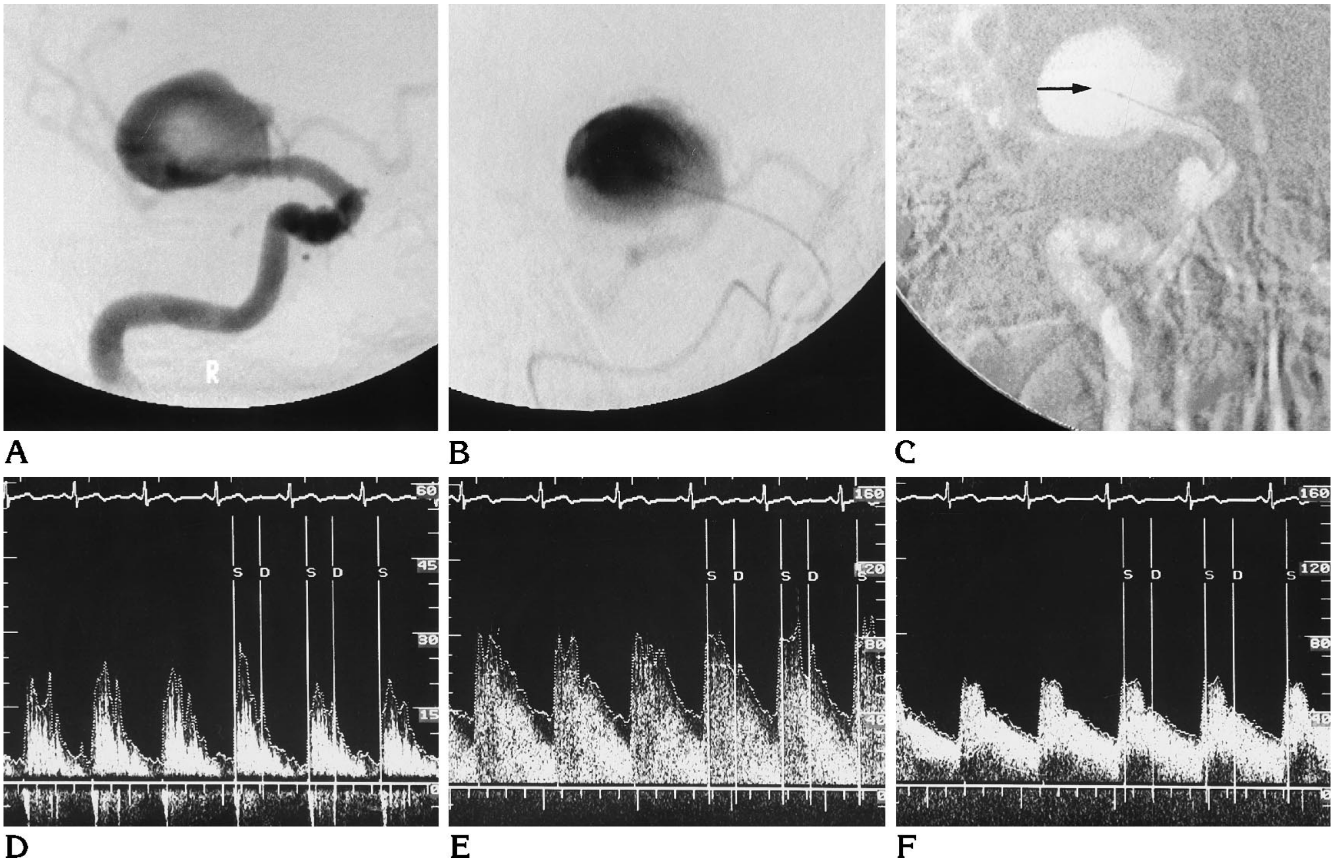

Fig 2. Case 1: 37-year-old woman with a large intracranial aneurysm.

A, Injection of the right internal carotid artery (ICA) in right anterior oblique projection shows a giant aneurysm originating from the distal ICA.

B, Superselective injection performed with a Tracker-18 catheter distinctly shows the origin of the aneurysm at the termination of the ICA. The relationship between the size of the neck and the size of the sac is shown. The neck is just between the right M1 and A1 segments.

C, The Smart Wire was introduced after the guidewire was withdrawn. A road map permitted us to avoid contact between the Doppler probe (*arrow*) guidewire and the aneurysmal wall. It also enabled us to determine the exact location within the vessel and aneurysm where the actual measurement took place.

D, Inside the aneurysm, near the wall of the dome, the systolic peak velocity was found to be relatively low (maximum peak velocity, 28 cm/s) and there was almost no diastolic velocity (average peak velocity, 10 cm/s), resulting in a high pulsatility index (2.5). The flow curve showed multipeaked systolic recordings and small flow phenomena around the baseline.

E, Flow at the neck of the aneurysm showed a significantly higher systolic peak velocity (maximum peak velocity, 88 cm/s) and higher diastolic velocity (average peak velocity, 59 cm/s), resulting in a lower pulsatility index (0.9).

F, Flow outside the aneurysm in the parent vessel (supraclinoid portion of the ICA) showed lower systolic peak velocity (maximum peak velocity, 57 cm/s), lower diastolic velocity (average peak velocity, 38 cm/s), and similar pulsatility index (0.9).

and a relatively low diastolic flow. The lowest systolic peak (maximum peak velocity, 33 cm/s) but the highest pulsatility index (2.0) was found at the position nearest the wall of the dome. By pulling backward and measuring continuously, an increased flow velocity could be observed, with the highest value in the neck (83 cm/s). Outside the sac, in the parent vessel, we found a lower flow velocity (maximum peak velocity, 50 cm/s). Flow pattern was pulsatile without signs of significant disturbances.

In both cases, the Doppler guidewire was applied safely and without side effects. During the measurements, the shape of the wire tip and of the microcatheter was not changed. The microcatheter was oriented according to the mean direction of blood flow into the sac. Thus, the assessed flow parameters represent the predominant hemodynamic situation in this area. On the other hand, the sample volume was relatively small compared with the diameter of both aneurysms (5 mm and 20 mm, respectively). Therefore, the measurements did not cover the whole intraaneurysmal flow profile, which is known to be rather complex. The relationship between the size of the wire/microcatheter and the size of the aneurysmal neck was such that changes of flow due to the device could be ignored.

Discussion

Flow patterns are of basic interest in the evaluation of the pathogenesis of growth and rupture of cerebral aneurysms (4–6). After surgical clipping or endovascular treatment, regrowth and recurrent bleeding are the primary risks for all patients. Prognosis in a given patient, particularly when the aneurysm is asymptomatic, is uncertain.

Pathologic mechanisms that are responsible for these problems are complex and still incompletely understood; however, the main contributing factors are hemodynamic, such as blood pressure and blood flow. Changes in blood pressure that result in radial stress on the aneurysmal wall are presumably responsible for acute injuries of the wall, causing rupture and bleeding. Increased flow velocities and disturbed flow pattern cause different shear stress at certain points on the aneurysmal wall and are probably major factors that influence aneurysmal remodeling. Blood flow may induce potential points of weakness in the aneurysmal wall and may determine where the aneurysm will grow or rupture and bleed. Better understanding of the basic pathophysiology of berry aneurysms is also necessary to optimize current and future endovascular treatment, as reported by Strother et al (4, 7).

There is no satisfactory method available yet for assessing hemodynamic flow within an aneurysm, and data from measurements obtained with Doppler guidewires could help improve this knowledge. Intraluminal in vivo studies of flow velocities within an aneurysmal sac might be of prognostic value in these patients. As shown in different experimental and animal studies (3, 4, 6), the highest flow velocities have been found at the necks of aneurysms. This finding supports the theory that the main hemodynamic stress factors, such as shear stress and vibrations for the vessel wall, are greater at the ostium than at the dome (3). Thus, processes of remodeling, growth, and regrowth should occur more often at the neck than at the dome (4).

This concept is consistent with the opinion that berry aneurysms represent an acquired degenerative disease induced by hemodynamic stress factors rather than congenital lesions (4–6). Hemodynamic stress and consecutive remodeling of the arterial wall are likely to be responsible for the development of aneurysms. It has been asserted by several authors (6, 8–10) that the intraaneurysmal flow pattern is not necessarily turbulent. Recently, Kerber and Liepsch (11) have clearly pointed out that fully turbulent flow is rare in humans. Rather, what is reported by many authors is a disturbed pattern of blood flow. Therefore, we avoid the term *turbulent* and prefer to speak of *disturbed* blood flow.

Conventional criteria for "turbulences," such as the filling in of the acoustic window, seem not to be applicable in the interpretation of flow measurements made with guidewires. The width of the sample volume is small (5 mm) in relation to our two large aneurysms (20 mm), and the sampled spectrum may be skewed. Disturbed flow in the aneurysm according to the criteria described in "Materials and Methods" was seen only near the wall, as shown in Fig 2E (irregularities of the IPV tracking line, broadening of spectra, small isotropic phenomena).

It is unclear whether the undisturbed part of the flow is more significant for producing acute injury (rupture) of the wall than is the disturbed flow in certain areas of the aneurysmal sac. By its direction, flow may create a force that impinges directly against the aneurysmal wall, eventually causing acute rupture. Estimating this impingement force on the basis of IPV velocity is possible and might be helpful in making a clinical prognosis.

The fact that pulsatility was clearly higher near the dome than at the neck or in the parent vessel in both our cases is explained sufficiently by low diastolic flow. Defined as the relationship between systolic and mean flow velocity, pulsatility is commonly an indicator of peripheral vascular resistance. Although this parameter was used to describe the increased flow resistance inside the sac by Harders (10), its relevance in aneurysms remains unclear. We also found multipeaked systolic recordings of flow to be typical for aneurysms (10), as compared with parent vessels.

The usefulness of Doppler guidewires in assessing flow information in cerebral arteries and dural sinuses has been reported for other studies (Benndorf G, Podrabsky P, Wellnhofer E, et al, "Measurement . . .") (Benndorf G, "Intraluminal Measurement of Cerebral Artery Flow Velocity by Intravascular Pulsed Doppler," presented at the annual meeting of the European Society of Neuroradiology, Bruges, Belgium, September 1993, and "Clinical Application of Arterial Blood Flow Velocity Measurements Using Doppler Tipped Guidewires, presented at the annual meeting of the European Society of Neuroradiology, Nancy, France, June 1994). As we found in the studies of other diseases, this system can be safely applied to the measurement of cerebral aneurysms. Careful handling is necessary to avoid contact between the Doppler probe and the aneurysmal wall, which otherwise could potentially cause rupture and bleeding. Mechanical properties of the Smart Wire have been improved and are now similar to those of other microguidewires commonly used for superselective catheterization of cerebral arteries and aneurysms. However, for the sake of maximum safety, we recommend using the Doppler guidewire as a measuring tool rather than as a guidewire. Moreover, high-quality road mapping to maintain a safe position of the Doppler probe with respect to the wall is mandatory.

One disadvantage of the Smart Wire technique is that it is difficult to stabilize the wire in certain portions of the aneurysm. With regard to the complex flow phenomena encountered, mapping of the whole intraaneurysmal flow may be impossible. Despite this limitation, Doppler guidewires seem to be useful in monitoring intraaneurysmal flow phenomena and might be of value in evaluating changes of flow after endovascular or surgical treatment.

Conclusions

Newly shaped, miniaturized Doppler guidewires (Smart Wire) with improved flexibility permit measurements of flow velocity and flow patterns in cerebral aneurysms during superselective angiography of interventional procedures. They are of potential value in the monitoring and follow-up of intracranial aneurysms treated by coils or surgery. Preliminary measurements reported in this study cannot address all concerns posed by use of this technique, but they may be helpful in planning and performing further investigations, which are necessary to determine its future role in interventional neuroradiology.

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