Parallel and Spiral Flow Patterns of Vertebral Artery Contributions to the Basilar Artery

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PURPOSE: To demonstrate that the in vivo flow from individual vertebral arteries can be imaged and tracked in the basilar artery by use of saturation planes with three-dimensional time-of-flight MR angiography. **METHODS:** Twenty volunteers were studied with intracranial three-dimensional time of flight angiography MR. The MR angiography was repeated with saturation of the individual vertebral arteries. Flow voids and signal intensity within the basilar and posterior cerebral arteries were evaluated for flow patterns. **RESULTS:** Of 15 volunteers with a "normal" vertebrobasilar anatomy, 80% demonstrated a pattern of flow within the basilar artery in which the contributing vertebral components remained ipisilateral. This pattern was called "parallel." A "spiral" pattern of rotation of the contributing vertebral components was found in 20% of studies. The inflow to the posterior cerebral arteries could be identified from specific vertebral contributions and was related to the size-dominance of the vertebral artery. **CONCLUSION:** There is nonadmixture of vertebral artery flows of variable duration within the basilar artery; at least two patterns of flow can be described within the basilar artery. The method presented is a simple technique for determining vertebral artery flow components with routine software and without secondary data manipulation.

Index terms: Arteries, flow dynamics; Arteries, vertebral; Magnetic resonance angiography

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"Normal" posterior fossa arterial anatomy is regarded as two vertebral arteries joining to form the basilar artery. One might have assumed that this anatomy means there is admixture of the inflow from the vertebral arteries as they join to form the basilar artery, which is subsequently distributed equally to the posterior cerebral arteries (PCAs). Students of flow dynamics would have told us this is a poor assumption. Recent studies by Chong et al have shown the complex and variable stream patterns within the vertebral and basilar arteries by use of dye streams in an anatomic model (1). This study presents a simpler approach to viewing flow within the basilar artery in living subjects and without complex postprocessing. This study was undertaken to evaluate whether magnetic resonance (MR) saturation methods could demonstrate flow patterns within the basilar artery attributable to individual vertebral artery contributions. Although we performed these experiments as an exercise of academic curiosity, we also thought that a relationship between basilar and vertebral flows might explain the asymmetry of contrast in the basilar and posterior cerebral arteries seen occasionally at catheter angiography and could be a tool in understanding the basic pathogenesis of atherosclerotic disease states.

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Materials and Methods

Twenty subjects, 19 healthy volunteers and 1 patient volunteer (23 to 72 years of age), were studied using three-dimensional time-of-flight MR angiography. A 1.5-T (Siemens, Erlangen, Germany) MR unit was used (5/40 [repetition time/echo time], flip angle 20°), with a 512 × 256 matrix. The routine MR angiography sequence was performed first. Presaturation planes then were placed within the MR angiography volumes to prevent flow-related enhancement within the vessel of interest. The

Basilar artery flow patterns and segregated vertebral artery contributions

Subject	Age, y	Vertebral Artery Dominance	PCA Contribution	Rotational Degree	Anatomy
Parallel Basilar Artery Flow					
1. F.D.	61	None	R→R only, L→L only	. . .	. . .
2. L.P.	40	None	R→R only, L→L only	. . .	. . .
3. T.H.	22	None	L→L + R, R→R only	. . .	. . .
4. A.H.	62	None	L→L > R, R→R > L	. . .	. . .
5. R.E.	23	None	(Not Determined)	. . .	. . .
6. T.L.	29	None	L→L > R, R→R > L	. . .	. . .
7. M.C.	66	L	L→R + L, R→none	. . .	. . .
8. P.H.	72	R	R→R > L, L→L only	. . .	. . .
9. S.R.	23	L	L→R + L, R→R only	. . .	. . .
10. L.G.	24	R	R→R + L, L→ none	. . .	. . .
11. R.V.	30	L	L→R + L, R→ none	. . .	. . .
12. F.C.	72	L	L→R + L, R→ none	. . .	. . .
Spiral Basilar Artery Flow					
13. J.M.	30	R	R→R + L, >L→R + L	240°	. . .
14. V.B.	32	L	L→R + L, R→R only	180°	. . .
15. F.K.	40	None	L→R + L, R→R only	180°	. . .
No Basilar Artery Flow Pattern					
16. D.J.	32	. . .	. . .	. . .	Very dominant L vertebral
17. V.G.	42	. . .	. . .	. . .	L vertebral ends in PICA
18. M.H.	66	. . .	. . .	. . .	R vertebral ends in PICA
19. R.V.	23	. . .	. . .	. . .	L vertebral ends in PICA
20. J.H.	24	. . .	. . .	. . .	R vertebral→PICA; bilateral fetal PCAs

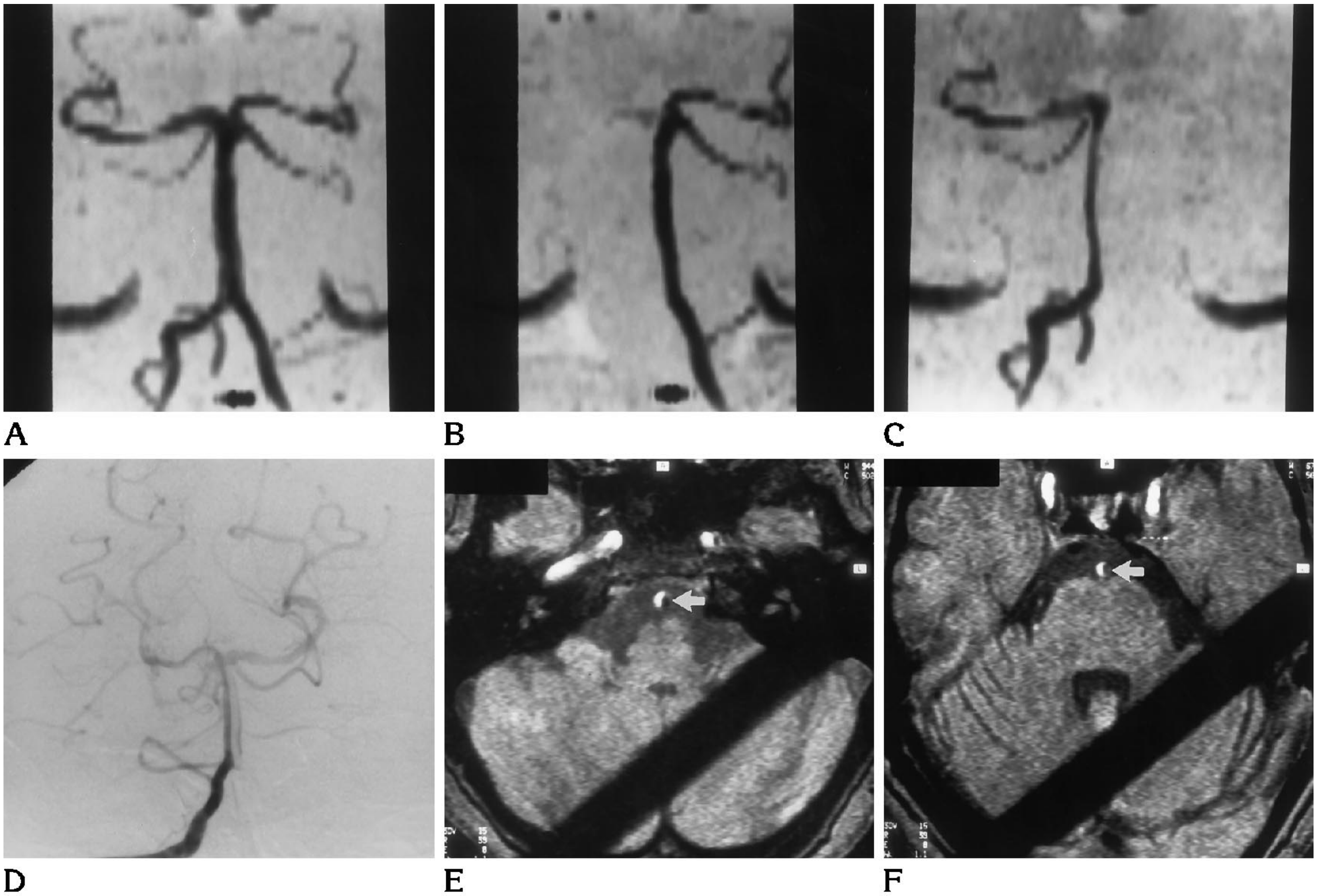
volume subjected to a "saturation" plane experienced a variable number of preparatory pulses in the case of 90° flip angle. These preliminary radio frequency pulses before the MR angiography sequence suppress the inflow enhancement experienced by unsaturated flow, leaving a flow void. The vertebral arteries were individually saturated at the level of the vertebral loop at C-2. The patient study had angiographic correlation. Images were evaluated to track the vertebral artery components of the basilar artery flow to determine potential patterns. The maximum intensity projection and source images were evaluated to follow the signal and flow void of the respective nonsaturated and saturated flows in the basilar artery and to determine the flow in the PCAs. Measurements of vessel-to-vessel angles were compared with basilar flow patterns. These measurements included the vertebrobasilar vessel angles in anteroposterior and lateral planes and vertebrovertebral angles in the anteroposterior plane. Relative vertebral size also was assessed, a "dominant" vertebral artery being one at least 30% greater in diameter. Flow was evaluated at a workstation (Siemens); angles were measured on film. Two observers participated simultaneously in the evaluations.

Results

Basilar Flow Patterns

Of the 20 volunteers studied, 1 showed only one vertebral artery contributing to the basilar artery flow, and 4 showed one of the vertebral arteries ending in a posterior inferior cerebellar artery (PICA). The latter configuration may actually be attributable to undetected flow in a small vertebrobasilar connection rather than the normal variant of a vertebral artery terminating in the PICA. In subjects who had two vertebral arteries contributing to the basilar artery, 15 (94%) of 16 showed an identifiable pattern of flow within the basilar artery, which indicated nonmixture of the vertebral components. The remaining volunteer showed marked size dominance of the left vertebral artery with no detectable flow from the right vertebral artery (Table).

Two patterns of flow were discerned. In the "parallel" flow pattern, flow remained ipsilateral for the majority or complete length of the basilar artery. This pattern was present in 12 (80%) of 15 of subjects who had a pattern of segregated vertebral contributions to basilar artery flow. Angiographic correlation in one subject showed an identical flow pattern of ipsilateral vertebral artery to basilar artery to PCA flow (Fig 1). The "spiral" flow pattern, in which the two flow components were seen to rotate rela-



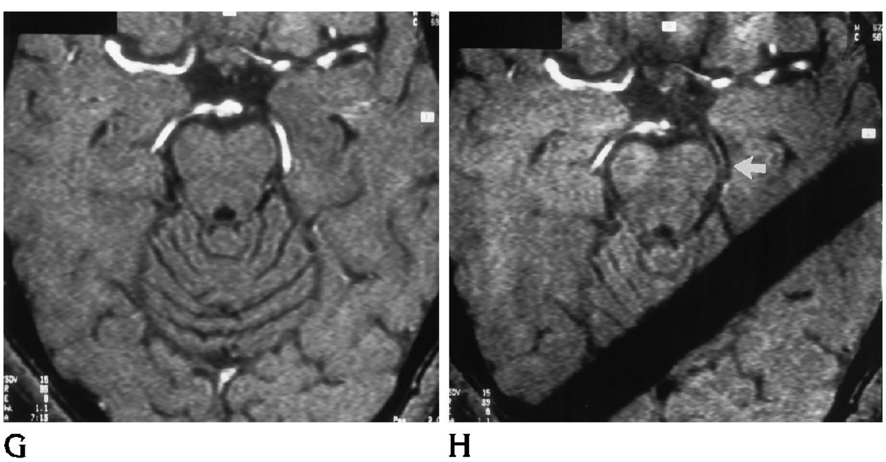


Fig 1. Parallel flow pattern of vertebral artery contributions to the basilar artery (case 1).

A, Anteroposterior view of the vertebrobasilar maximum intensity projection.

B, Right vertebral flow has been selectively saturated. The MR angiogram shows flow from the left vertebral artery along the left side of the basilar artery to the left PCA and SCA.

C, The left vertebral artery has been selectively saturated. Right vertebral artery flow is seen along the right side of the basilar artery and exclusively to the right PCA and right superior cerebellar artery.

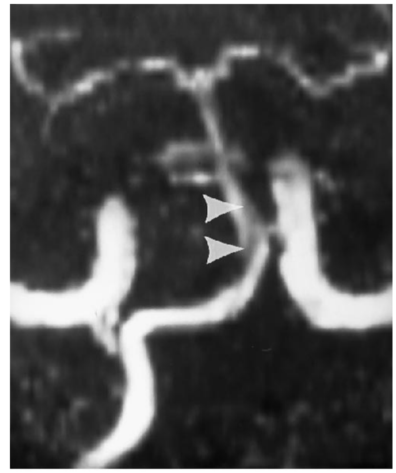
D, Anteroposterior vertebral angiogram shows contrast from the right vertebral artery and nonopacified blood from the left vertebral artery coursing in a parallel pattern through the basilar artery.

E and *F*, Images through the medulla (*E*) and midpons (*F*) show persistence of the parallel flow with saturation of the left vertebral artery. Left vertebral artery saturation is reflected as the flow void within the left side of the basilar artery (*arrows*).

G, Source image from unsaturated MR angiography at the level of the posterior cerebral arteries.

H, Source image with saturation of the left vertebral artery shows absence of high signal in the left posterior cerebral artery (*arrow*).

tive to the vertebral entry points, was seen in 3 (20%) of 15 of subjects with a segregated flow pattern. The degrees of rotation of flow in the "spiral" for these subjects were 180°, 180°, and 240° (Fig 2). Dominance or nondominance of the vertebral artery size was not contributory to prevalence of the spiral versus the parallel flow patterns in this small series. No relationship of basilar flow patterns could be made to vessel-vessel angles.



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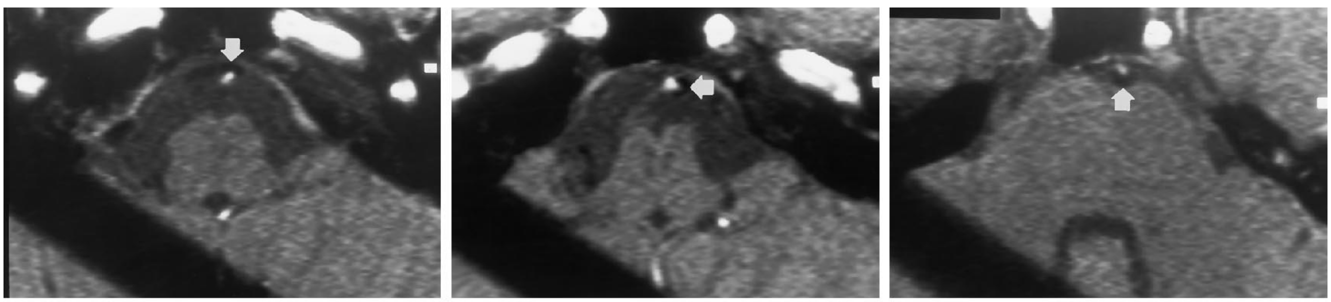

B C D

Fig 2. Spiral flow pattern of the vertebral artery contributions to the basilar artery (case 13).

A, On the maximum intensity projection of the vertebrobasilar system, saturated blood from the left vertebral artery results in an oblique flow void in the proximal basilar artery (*arrowheads*).

B–D, Source images from MR angiography show the flow void from the saturated right vertebral artery (*arrows*) as it rotates from anterior (*B*) to left-lateral (*C*) to posterior (*D*) within the basilar artery.

Evaluation of PCAs

In patients with a size-dominant vertebral artery in which PCA contribution was determined (8), the PCAs received the majority of flow from the dominant artery in 8 of 8 cases. However, the nondominant artery component contributed only to the ipsilateral PCA in three studies. In one case both dominant and nondominant components contributed to both PCAs (case 13). In patients without a size-dominant vertebral artery, in which PCA contributions were determined (6), two cases had exclusively ipsilateral flow (Fig 1). In two cases (4 and 6) contributors of each vertebral artery went to both PCAs. In the two cases (3 and 15), flow from one vertebral went to both PCAs, while the remaining vertebral artery contributed ipsilaterally to the PCA.

Discussion

A pattern of parallel or spiral flow within the basilar artery after selective injection of a vertebral artery has been observed by most neuroangiographers. However, most vertebrobasilar catheter angiograms are performed with contrast pressure or volume sufficient to opacify homogeneously the basilar artery and both posterior cerebral arteries. This study was performed to verify the theory that vertebral contributions to the basilar artery would remain separate, because blood is a noncompressible liquid. The ability to distinguish two patterns of flow within the basilar artery was not expected. The side-by-side progression of vertebral artery flow components in the basilar artery, which was termed "parallel," was present in 80% of the volunteers (Fig 1). The term "spiral" flow was used when the vertebral flow components appeared to rotate more than 90° relative to the entry sites (Fig 2). This pattern was seen in 20%. The degree of rotation for the three patients varied at 180°, 180°, and 240°. This pattern correlates with the helical pattern found at the vertebral confluence in the dye injection studies by Chong et al (1). The fact that the PCA can be exclusively or preferentially fed by a specific vertebral artery may explain the ability of a process affecting only one vertebral artery to affect only one PCA distribution. An example would be emboli from a vertebral dissection or area of atherosclerosis repeatedly resulting in strokes or transient ischemia in the same distribution. The superior cerebellar arteries were not seen on the saturated images with enough consistency to be evaluated. However, it is of interest that the superior cerebellar arteries observed in case 1 (Fig 1) also showed ipsilateral inflow with a parallel basilar flow pattern.

Three-dimensional flow patterns have been described for several human vessels, which differ by the angle of feeding vessel, relative size of feeding vessel, and areas of stenosis or tortuousity. Disturbed flow associated with a particular vessel geometry have been found to play an important role in the location of thrombosis and atherosclerosis and result in vessel wall damage (2–4). Specifically, atherogenesis appears to be affected more by the presence of low velocity, nonlaminar flow with fluctuating shear stress rather than by the amplitude of the shear stress. In other words, unsteady blood flow characteristics, rather than the magnitude of wall shear stress per se, may be the major determinant of hemodynamically induced endothelial cell turnover, a precursor to plaque formation (3, 4). Such flow characteristics presumably allow prolonged contact of vessel wall with platelets, granulocytes, and metabolites that influence atherogenesis. Furthermore, aneurysm formation and vessel wall dilatation have been found in areas of disturbed flow (2). Unfortunately, this specific information has not been correlated to the vertebrobasilar system. Potentially, vertebrobasilar flow patterns could be generated from simulated streamline methods based on computer projections of velocity vectors, as have been done in other vessels (5). However, the method in this study relies on routine imaging techniques with readily apparent visual results on the source images and without secondary data manipulation. The components of vertebral contribution were more obvious on the source images than on the maximum intensity projections, although both are useful.

The source of flow in the posterior cerebral arteries relative to the contributing vertebral artery usually was apparent and had at least some relationship to the pattern of flow within the basilar artery and relative size of vertebral arteries. In cases in which the basilar artery flow pattern was parallel, the source of flow to the posterior cerebral arteries depended on the presence or absence of size dominance of one of the vertebral arteries. The flow of the PCA was predominantly from the ipsilateral vertebral artery when the vertebral arteries were of approximately the same size. In the presence of a size-dominant vertebral artery, both PCAs received the majority of their flow from the dominant side. Interestingly, the nondominant vertebral artery component flowed only to the ipsilateral PCA in the 37% of cases.

In summary, by using a saturation plane within the MR angiographic volume, we were able to determine a pattern of flow within the basilar artery from the inflow of the respective vertebral arteries in 94% of subjects with normal vertebrobasilar anatomy. The majority (80%) showed a side-by-side parallel pattern, the minority (20%) a spiral pattern. The vertebral components of posterior cerebral artery inflow also can be demonstrated. Although this information is presented as an observation, it allows for speculation regarding the relationship of atherosclerosis to basilar flow patterns in view of the body of knowledge about plaque formation and flow dynamics. The sidedness of posterior cerebral artery disease also might be attributed to a single vertebral artery source.

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