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AJNR Am J Neuroradiol 1998, 19 (4) 691-693
http://www.ajnr.org/content/19/4/691

AJNR Am J Neuroradiol 19:691–693, April 1998

Velocity-Coded Color MR Angiography

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Summary: We developed a method of velocity-coded color MR angiography using a color code from the data obtained from velocity-phase images of phase-contrast MR angiography in order to add flow direction information to MR angiograms. Phase-contrast MR angiography with reconstruction of velocity-phase images was performed in 30 patients. Two projection images from velocity-phase images of each phase-contrast MR angiogram were obtained and assigned color according to flow direction. We then superimposed the two color images onto the maximum intensity projection image of the MR angiogram. The velocity-coded color MR angiogram clearly showed flow direction from the data on the phase-contrast MR angiogram of the neck. Veins were readily distinguishable from arteries, and flow changes, such as a subclavian steal, were also identified.

Magnetic resonance (MR) angiography has rapidly become an excellent method for studying patients with cerebrovascular disorders (1–12). The three-dimensional time-of-flight (TOF) technique has become the mainstay because of its higher resolution and shorter acquisition time (13). Phase-contrast MR angiography provides information about the anatomy of vessels and depicts flow direction and velocity (14–18).

We present our findings with velocity-coded color MR angiography in which we used color-coded data from velocity-phase images of phase-contrast MR angiography.

Methods

We studied 30 consecutive patients with suspected abnormalities of the brain or head and neck who were referred to our department for MR imaging/MR angiography. Five patients were determined to have no disease, eight had tumors in these regions, and 17 had vascular disorders. Fifteen of the 30 patients were also studied by conventional angiography (head and neck).

Imaging included two-dimensional phase-contrast sequences with parameters of 20–40/6–9/1–2 (repetition time/echo time/excitations), a flip angle of 20°, a velocity-encoding value (VENC) of 30 to 70 cm/s, and a section thickness of 4 to 10 mm; and/or 3-D phase-contrast sequences with parameters of 20–33/6–7/1, a flip angle of 20°, a VENC of 30 to 50 cm/s, a section thickness of 1.2mm, a field of view of 20 to 30 cm, and a matrix of 256–512 × 128–192. All sequences were performed on a 1.5-T MR unit. Eleven of the 30 patients were studied with a 2-D phase-contrast sequence, and 23 with a 3-D sequence. In addition to source images for routine MR angiography, we planned for and reconstructed velocity-phase images in the superior-inferior direction. Acquisition time was the same as for the scan without velocity-phase images, but reconstruction times were doubled. The velocity-phase images had negative or positive values. Negative values meant an inferior-to-superior flow direction and positive values meant a superior-to-inferior direction.

We obtained maximum intensity projection (MIP) and minimum intensity projection (MinIP) images from the velocity-phase images of phase-contrast MR angiography using an independent workstation. These three images (MIP and MinIP images from velocity-phase images and an MIP image from MR angiography) were projected in the same direction (usually anteroposterior) with the same matrix size. The three images were then transferred to a personal computer for coloring using graphic software (Photoshop 3.0, Adobe Systems, Mountain View, Calif). Gray-scale images of the MIP or MinIP images of the velocity-phase images were assigned either red or blue, and then the two color images were superimposed onto the MR angiogram using the Photoshop software. The velocity-coded color MR angiograms were subjectively compared with the gray-scale MR angiogram by three radiologists for visibility of small vessels, flow direction, and overall diagnostic value.

Results

After the MIP and MinIP images from the velocity-phase images were reconstructed using a phase-contrast MR angiographic pulse sequence on the workstation (3 minutes per MIP/MinIP, including date loading/saving time), color coding was performed easily on a personal computer (10 minutes per one-color MR angiogram). The velocity-coded color MR angiogram showed flow direction from the data on the 2-D or 3-D phase-contrast MR angiogram of the head and neck. Veins were readily distinguishable from arteries (Fig 1). Retrograde flow of the vertebral arteries in two patients with subclavian steal was seen as blue (Fig 2), indicating opposite direction of flow. In a case of occlusion of the superior sagittal sinus (at the parietal segment by a residual meningioma), retrograde flow of the patent anterior segment of the sinus was visible on the velocity-coded color MR angiogram (Fig 3). Complicated flow direction of the feed-

Received February 12, 1997; accepted after revision June 13.

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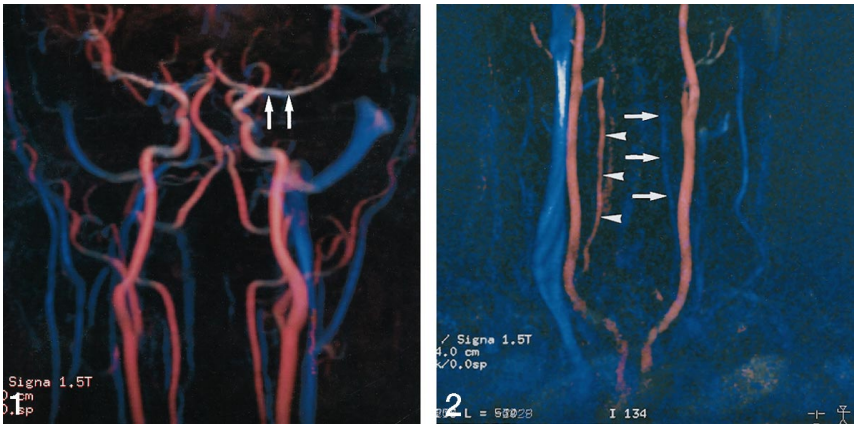

FIG 1. Normal velocity-coded color MR angiogram (frontal view) (33/7/1). Blue was added to the MIP image, which has superior-inferior flow direction, and red was added to the MinIP image, which has inferior-superior flow direction. Most veins are displayed in blue and most arteries in red. Segments of the vessels without superior-inferior flow remain gray (*arrows*) because we coded only superior-inferior flow.

FIG 2. Color MR angiogram of subclavian steal (frontal view) (26/7/1). Retrograde flow in the left vertebral artery in a patient with a subclavian steal is shown in blue (*arrows*), indicating opposite flow direction. Note that the right vertebral artery is red (*arrowheads*), indicating normal flow direction.

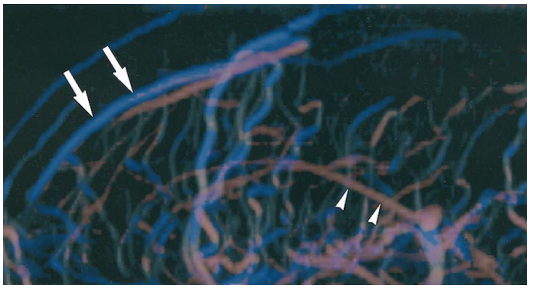

FIG 3. Color MR angiogram (lateral view) (26/7/1) of superior sagittal sinus occlusion by a residual meningioma. Retrograde and normal flow in the patent anterior segment of the superior sagittal sinus (*arrows*) is shown as blue by velocity-coded color MR angiography using velocity-phase images in the anteroposterior flow direction. In this case, we colored the anteroposterior flow red (see inferior sagittal sinus: *arrowheads*) and the posteroanterior flow blue.

ing and draining vessels of arteriovenous malformations and hypervascular tumors (two glomus tumors, two meningiomas, and one angiofibroma) was demonstrated as vessels with different colors within and adjacent to the lesions.

In 25 of the 30 patients, velocity-coded color MR angiograms showed small vessels with nearly equal clarity as that on the gray-scale MR angiograms. Background noise was increased with this preliminary method, and small branches were occasionally diminished in caliber (in five patients). Overall, the diagnostic accuracy of color MR angiography was judged equal to that of gray-scale MR angiography.

Discussion

In previous studies, the method of flow analysis with phase-contrast MR angiography was mainly through the source images (2–4, 16–18). Each velocity-phase image was suitable for analysis, but not for practical interpretation. When this flow information is put to use in a practical fashion, phase-contrast MR angiography may become superior, or at least complementary, to TOF MR angiography. Our velocity-coded color MR angiographic method, which uses a color code from data obtained from velocity-phase images of phase-contrast MR angiography, gives the interpreter the ability to view anatomic structures as well as velocity/flow direction on a single image.

Three-dimensional phase-contrast MR angiography provides four sets of images: x-axis (left-right), y-axis (posteroanterior), and z-axis (inferior-superior) velocity, and total speed images. The intensity of the total speed images is related to the magnitude of the sum of the vectors of the velocity in each direction. Three sets of velocity-phase images may be obtained, one of which contains directional and velocity information along the three axes. The velocity-phase images contain negative and positive values; negative values represent one direction along the axis and positive values represent the opposite flow direction along the same axis. The projection technique of these velocity-phase images requires an MIP and an MinIP technique or another technique, such as an absolute value algorithm (14) or collapsed images (15). The MinIP projects negative values that have the largest absolute value. By using MIP and MinIP techniques on the same set of velocity-phase images, one can produce two different images that show opposite flow.

Only one direction (usually, superior to inferior) was colored in our study. In the head and neck, information on this one direction may provide sufficient clinical data, because most arteries run distally and veins run proximally. Using red color for distally directed flow makes most arteries red, whereas using blue color for proximally directed flow makes most veins blue.

Several coloring methods have been used with imaging studies to obtain additional information, such as flow direction (19–22); but of all these techniques, color Doppler sonography is the most successful. With it, one may display up to three different parameters without theoretical loss of contrast, because humans have three different color receptors in the retina (19). With MR imaging, different parameters (19, 20), diffusion tensor (21, 22), phase-contrast MR angiography, MR spectroscopy, and functional MR

imaging may be effectively presented by using a color display. The reason some of these multicolor display methods have not yet become popular may be due to patient motion during imaging and to the fact that these artificially colored images are less familiar to interpreters. Our velocity-coded color MR angiograms are obtained from the same phase-contrast acquisition and have no significant misregistration between imaging components.

Velocity aliasing, which occurs when true velocities exceed the peak VENC, may occur with our velocity-coded color MR angiographic method, similar to that encountered with conventional phase-contrast MR angiography. In such cases, flow can be incorrectly shown as being in the opposite direction. However, we think that velocity aliasing is easily recognized by the extreme values of adjacent pixels and by its location within the vessels. Within the VENC setting of this study (30–70 cm/s), velocity aliasing did not significantly deteriorate image quality.

In conclusion, velocity-coded color MR angiography displays both anatomic and flow information on a single image. This may expedite interpretation of flow direction and flow velocity changes.

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