

Contrast-Enhanced MR Angiography of Failing Hemodialysis Arteriovenous Fistulas and Grafts: A Preliminary Experience¹

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Purpose: The purpose of this report is to evaluate the vascular stenosis for failing hemodialysis arteriovenous fistulas and grafts using contrast-enhanced MR imaging (CE-MRI) and to compare the results with digital subtraction angiography (DSA).

Materials and Methods: Nine patients (27 segmental vessels) with symptoms and signs of AVF stenosis or occlusion who presented to our medical department were recruited into this prospective comparative study. All of the patients with Brescia-Cimino arteriovenous fistula (AVF) or synthetic polytetrafluoroethylene (PTFE, Goretex) loop graft underwent MRA and DSA of the fistula. MRA was performed with a 1.5-T system using VIBE sequence: TR/TE = 3.5/1.5 msec, flip angle 20 - 25 °, matrix 115 × 256, FOV 350 × 350, interpolated slice thickness 2.0 mm, fat suppression, scan time 13 - 18 sec and total time of 5 min. DSA was used as the reference standard for assessing the accuracy of MRA, and MRA was analyzed for the presence of stenosis or occlusion, a grading of stenosis, and the presence of collateral vessels. Two radiologists prospectively analyzed the MRAs by working in consensus.

Results: Regarding the stenotic grade, CE-MRA corresponded with the DSA in six patients (66.7%) and it overestimated the stenoses in three patients (33.3%). For the stenotic site, MRA had a sensitivity of 86.4%, a specificity of 40%, a positive predictive value of 32.1%, and a negative predictive value of 66.7%.

Conclusion: Multiphase CE-MRA of the AVF noninvasively provided information comparable to that provided by DSA for the vascular stenosis regarding failing hemodialysis arteriovenous fistula.

Index words : Fistula, arteriovenous

Magnetic resonance (MR), three-dimensional

Magnetic resonance (MR), vascular studies

Digital subtraction angiography

It is very important to detect failing hemodialysis arte-

riovenous fistula as early as possible because the early treatment of stenoses by percutaneous intervention has been shown to increase the longevity of the dialysis shunts (1, 2). In current clinical practice, detection and grading of the stenosis are usually performed using color doppler sonography and digital subtraction angiography (DSA) (3, 4). Color doppler sonography is obviously the first choice of diagnostic method and it can non-invasively demonstrate failing hemodialysis arteriovenous

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fistulas, including stenosis, thrombosis, arterial steal and aneurysmal formation. However, color doppler also has some limitations: it is dependent upon the skill of the examiner, and it is difficult to distinguish between the very slow moving blood flow due to a severe stenosis and that of the occlusion; it is also difficult to detect collateral vessels around the prestenotic area (5, 6).

Although DSA and color doppler sonography have been the preferred methods for observing failing hemodialysis arteriovenous fistula, magnetic resonance angiography (MRA) may also be an attractive non-invasive method for evaluating dysfunctional hemodialysis access. Varying results have been published concerning the ability of MRA to detect the stenoses in AVF by using time-of-flight (TOF) (7), phase contrast (PC), and contrast-enhanced MRA (CE-MRA) (8, 9) techniques. A major problem with the flow-based approaches to MRA, such as TOF and PC, has been the frequent occurrence of flow artifacts in regions with disturbed blood flow, and these artifacts can complicate interpretation of the MRA (7). Compared with TOF and PC, CE-MRA is less sensitive to these artifacts and has provided better results (10, 11). However, there has been only limited information reported on its use in the literature.

The purpose of this study was to evaluate the feasibility of using CE-MRA for failing hemodialysis arteriove-

nous fistulas and grafts.

Materials and Methods

Patients

Nine patients who presented to our medical department with symptoms and signs of AVF stenosis or occlusion were recruited for this prospective comparative study. If the absolute AVF flow at any time was <600 ml/minute or if a patient exhibited a flow decline of >25% between two consecutive measurements in combination with an absolute flow of <1000 ml/minute, then the fistula was considered at risk for thrombosis (11). All of the patients (4 men and 5 women, aged 32 - 72 years; mean age: 53.1 years) had a Brescia-Cimino arteriovenous fistula (AVF) ($n=5$) (Fig. 1) or synthetic polytetrafluoroethylene (PTFE, Goretex(r)) loop graft ($n=4$) (Fig. 2), and they all underwent MRA of the fistula, and within four days, digital subtraction angiography (DSA).

Digital subtraction angiography (DSA)

All the DSA examinations were performed by one experienced angiographer (YMH) with the use of an angiostar (Simens, Muchen, German). Vascular access was examined by using high-frequency (7.0-MHz) color ul-



Fig. 1. MIP of a multiphase CE-MRA and DSA of a radiocephalic AVF obtained from the left arm of a 33-year-old male patient.

A. On the CE-MRA, multiple severe stenoses are viable in the cephalic vein.

B. CE-MRA of the severe venous stenosis is shown with the corresponding DSA. The patient did not undergo percutaneous angioplasty due to the multiple, long stenoses.

trasonography (US) (ATL, WA, U.S.A.) and the puncture site was chosen to be as far away as possible from the anastomosis. To access the collapsed fistula, a sterile latex tourniquet was placed tightly on the upper arm or shoulder region. The fistula was punctured with an 18-gauge cannula sheath, and this was generally done under US guidance. A 0.035-inch hydrophilic guide wire and a 7F vascular sheath (Cook, Bloomington, IN, U.S.A.) were introduced in a retrograde fashion. Angiography was performed by means of a hand injection of 5 - 10 ml of dilute iohexol (Visipaque 320, Nycomed Amersham, Cork, IRELAND) through the vascular sheath. Based on the CE-MRA and DSA, seven patients underwent percutaneous angioplasty (PTA) and two patients underwent surgical treatment.

Contrast-enhanced MR angiography using a volumetric interpolated breath-hold examination (VIBE)

MRA was performed with a 1.5-T system (Symphony; Siemens, Erlangen, Germany) by using a torso phase array coil or surface coil. The coil was placed over the patients so as to extend from the shoulder to the hand. We used a coronal contrast enhanced three-dimensional (3D) VIBE sequence: TR/TE=3.5/1.5 msec, flip angle 20 - 25°, matrix 115 × 256, FOV 350 × 350, interpolated slice thickness 2.0 mm, fat suppression, scan time 13 - 18 sec and total time of 5 min. An intravenous catheter was placed in the contralateral antecubital or forearm vein prior to the start of the study, and it was attached to an MR-compatible power injector (Spectris; Medrad, Pittsburgh, U.S.A.). At the exact same time that the CE-MRA commenced, the injection of contrast medium (Magnevist, Schering, Korea) was started. The injection rate for the contrast medium without saline injection was set at 3.0 mL/second at a dose of 0.1 mmol/kg. Since

a multiphase technique was used, the image acquisition was started together with the injection of contrast medium so that no additional timing of the contrast medium's arrival in the AVF was need. This allowed the estimation of patient circulation time to ensure the optimal timing of the arterial phase imaging using MR fluoroscopy. The VIBE images were obtained before administration of contrast material and also during the arterial, venous, and equilibrium phases of contrast enhancement.

Image processing and data analysis

Post-processing of the fat-saturated 3D VIBE images was performed on a commercially available MR workstation. One investigator (YSL) evaluated the overall images and performed reformations of the data sets before and after contrast administration. To increase the vessel-to-background contrast, the first (non-enhanced) 3D volume was later subtracted on a partition basis from the subsequent identical scans that were obtained during the presence of contrast material. The subtraction was performed using commercially available software (Windows NTR, Siemens, Erlangen, Germany). Compressing the subtracted images of each phase by means of maximum intensity projection post-processing created a dynamic subtraction contrast-enhanced MR angiogram.

The vessels of the upper extremity and the AVF were subdivided into three segments for analysis: the arterial segment, the anastomosis site and the venous segment. Two radiologists (GYJ, YMH) prospectively analyzed the MRA by working in consensus. The DSA was used as the reference standard for assessing the accuracy of the MRA, and the MRA was analyzed for the presence of stenosis or occlusion, and a grading of stenosis and

Table 1. Summary of the Stenoses Identified with Digital Subtraction Angiography and Magnetic Resonance Angiography

N	Age/Sex	Type of Hemodialysis access	Location of stenosis	Grade of stenosis		Collateral vessel	
				MRA	DSA	MRA	DSA
1	32/F	BC	AS, vein	III	III	(+)	(+)
2	33/M	BC	AS, vein	III	III	(+)	(+)
3	68/M	GRAFT	AS	I	I	(+)	(+)
4	72/F	GRAFT	Intragraft	Occlusion	Occlusion	(-)	(-)
5	39/F	GRAFT	Intragraft	Occlusion	III	(-)	(-)
6	46/F	BC	AS, artery, vein	III	III	(-)	(-)
7	60/F	BC	AS, vein	III	II	(+)	(+)
8	75/M	GRAFT	Intragraft	Occlusion	Occlusion	(-)	(-)
9	53/M	BC	AS, artery, vein	Occlusion	III	(-)	(-)

*AS=anastomosis site, BC=Brescia-Cimino arteriovenous fistula, GRAFT=synthetic polytetrafluoroethylene loop graft, MRA=magnetic resonance angiography, DSA=digital subtraction angiography

the presence of collateral vessels. A stenosis was diagnosed if there was a focal narrowing: grade I was less than 25%, grade II was from 25% to 75%, and grade III was greater than 75% luminal reduction. If multiple stenoses existed, the most severe stenosis was assessed. Occlusion was diagnosed if there was complete luminal signal loss within a patent vessel.

Statistical Analysis

The sensitivity and specificity of MRA for the detection of AVF stenosis were calculated using DSA as the reference standard.

Results

There were 27 vessel segments available in 9 patients for the analysis with CE-MRA, and CE-MRA was successfully completed in all nine of these patients. Regarding the stenotic grade, the CE-MRA corresponded with the DSA in six patients (66.7%) and it overestimated the stenoses in three patients (33.3%) (Table 1). For the stenotic site, MRA had a sensitivity of 86.4%, a specificity of 40%, a positive predictive value of 32.1% and a negative predictive value of 66.7%. Collateral or engorged vessels were demonstrated in four patients

having either a Brescia-Cimino arteriovenous fistula ($n=3$) or loop graft ($n=1$). CE-MRA showed findings similar to DSA in all four of these patients. Collateral or engorged vessels usually emerged from a prestenotic area in a vein.

Seven patients underwent successful percutaneous angioplasty and thrombolysis, and two patients had to be taken to surgery. One patient had severe engorgement or collateral vessels at the prestenotic venous site. Although we performed percutaneous angioplasty on the stenotic area, the thrill didn't completely disappear. After carefully reviewing the MRA and DSA, we performed ligation of a side branch among the prestenotic vessels, and this caused a marked improvement of the thrill.

Discussion

In this preliminary study, multiphase CE-MRA of the AVF provided non-invasive information comparable to the information provided by conventional angiography. It was also a quick and easy examination that produced high-quality images. We can suggest that multiphase CE-MRA is a reliable and reproducible tool for the detection of flow-limiting stenoses that occur in hemodial-

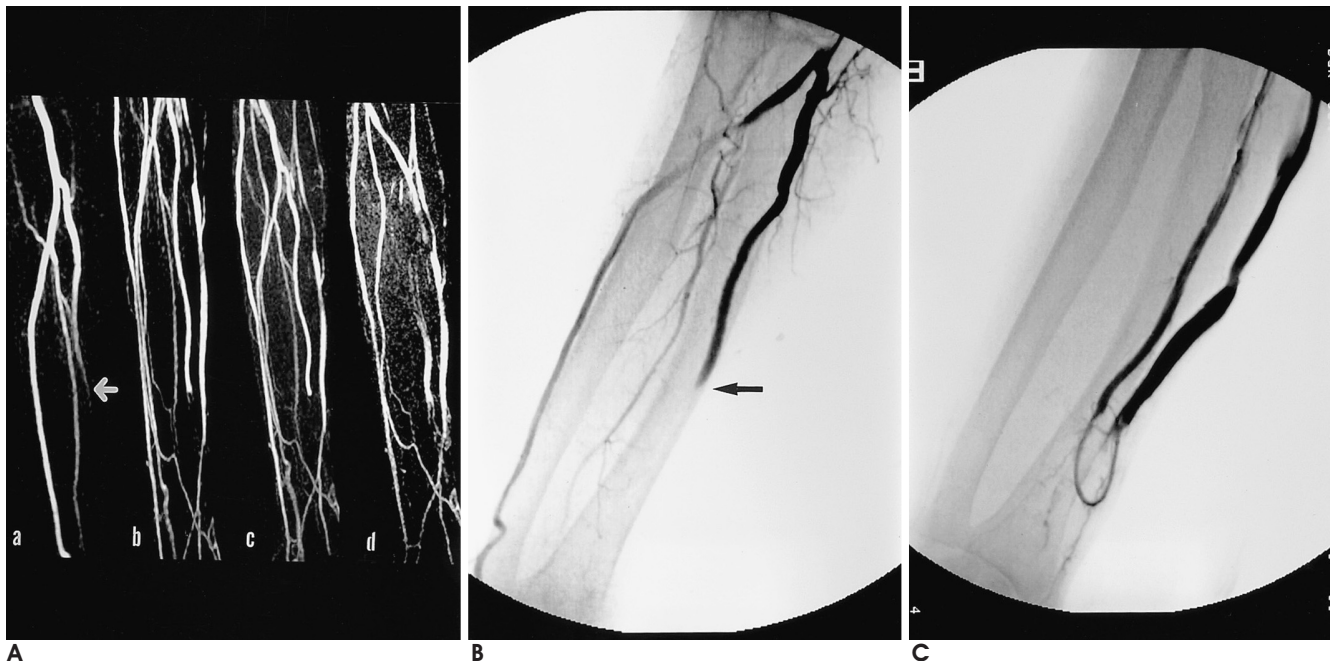


Fig. 2. MIPs of a four phase CE-MRA (13 second intervals) and the DSA of a U-loop PTFE graft AVF obtained from the left arm of a 75-year-old male patient.

A. On oblique coronal view of a multiphase CE-MRA, occlusion of graft is shown (arrow).

B. CE-MRA of the occlusion site is shown with the corresponding DSA.

C. After we performed percutaneous angioplasty and thrombolysis on the stenotic area, the graft was patent on DSA.

ysis AVF (11).

In general, multiphase CE-MRA has some advantages; 1) it is not dependent upon a skillful examiner, 2) the patient is not exposed to ionizing radiation, 3) it is not contraindicated for patients with impaired renal function, 4) it takes a short time (15 - 20 min), and 5) the blood flow rate can be measured. However, multiphase CE-MRA still has some disadvantages. The field of view is limited due to the use of a surface coil. Also, CE-MRA detected a relatively large number of false positive lesions and the overestimation of stenosis can still not be avoided (10, 11).

In this study, we performed CE-MRA using VIBE. VIBE is a 3D gradient-echo MRI technique tailored towards minimizing partial volume artifacts and maximizing the image contrast. The VIBE sequence is achieved by asymmetric k-space sampling in the readout direction and zero-filling in the section-select direction. The asymmetric echo in the read direction produces sharper images with fewer ringing artifacts and this permits the use of a narrower bandwidth. As a result, this sequence improves the SNR and the inplane spatial resolution. With VIBE, it's possible to use thinner sections than for the other sequences used for body MR, and this enables the use of fat saturation with a minimum of added imaging time. Therefore, very small caliber evaluations are feasible, and fat saturation improves the enhancement of vascular structures on gadolinium-enhanced MR angiography. With those advantages of VIBE, we successfully obtained good MR angiography results similar to those of DSA (13 - 18).

We suggest that this method is useful for evaluating venous stenosis or obstruction for the failing hemodialysis arteriovenous fistula before the interventional procedure. Although the optimal venous anatomy for AVF development is a single cephalic vein, in many cases the cephalic vein may have one or several accessory veins. In all our cases, the patients who underwent Brescia-Cimino arteriovenous fistula had a stenotic vein and anastomosis site. Venous stenotic sites that occurred after repeated needle punctures could have caused decreased thrill and decreased blood flow. As a result, this can cause anastomotic occlusion. According to Liang et al. (1), retrograde catheterization is usually not feasible for thrombosed AVFs that have coexisting venous stenosis and accessory veins. According to Hunter et al. (19), nine of 28 occlusions could not be crossed despite aggressive attempts from multiple directions. In our cases, PTA was not performed in two patients because they

had multiple stenoses and multiple collateral veins. Hence, although it is very important to detect failing vascular access as early as possible for successful PTA, it is necessary to accurately evaluate the venous stenotic sites and any prestenotic vessels by using CE-MRA.

There were a few limitations with this study; first, we only had a small number of study patients. Therefore, the sensitivity and specificity of this MRI technique could have been affected by the small size of the patient group. Second, it's expensive to perform MRA. Third, 3D-contrast MRA still overestimated severe stenosis. In conclusion, CE-MRA of the AVF provided non-invasive information comparable to that provided by DSA for the vascular stenosis regarding the failing hemodialysis arteriovenous fistula. In the future, the use of CE-MRA will make it possible to provide more information regarding the failing hemodialysis arteriovenous fistula and it will help the physician classify those patients who are candidates for PTA.

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