

“Dynamic” Time-Resolved Large FoV 3D MRA*

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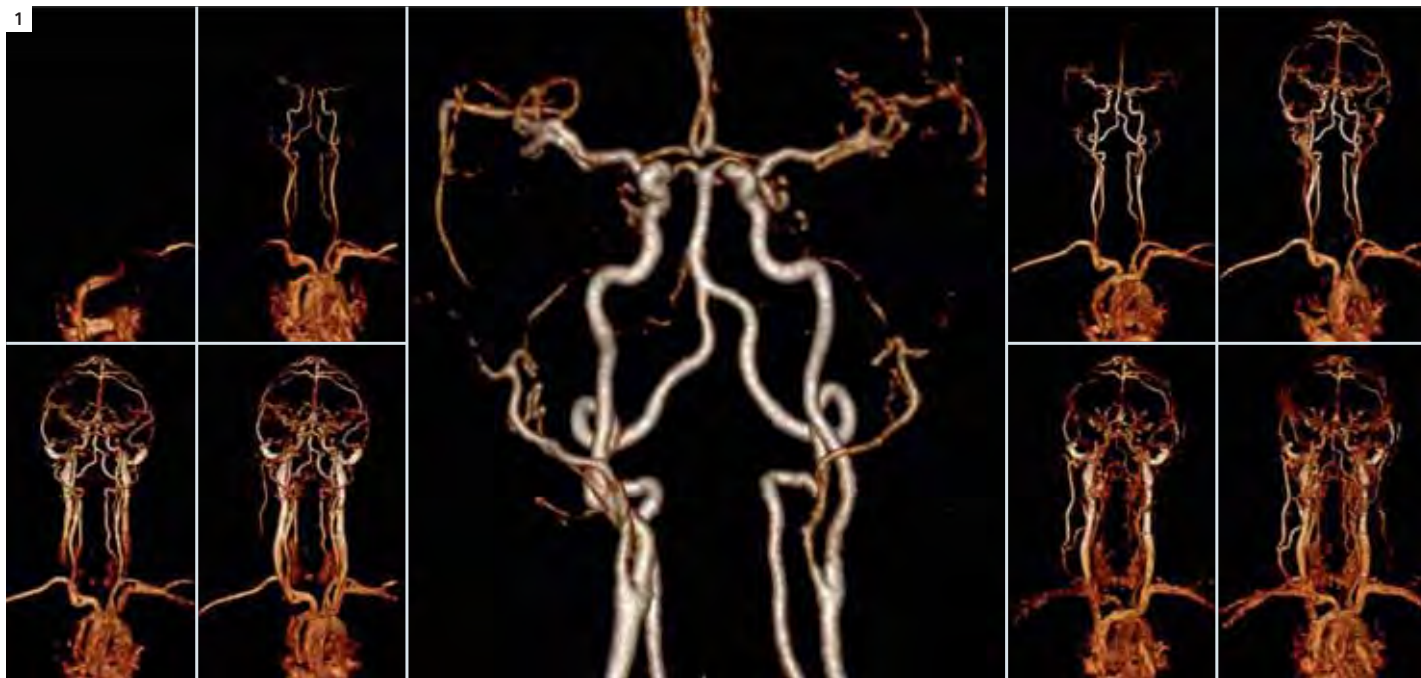
Introduction

Contrast-enhanced MR-angiography (ce-MRA) has largely influenced angiographic diagnostics throughout the past two decades [1]. Despite recent reports about contrast agent side effects ce-MRA remains a safe and easy procedure. With its high sensitivity and specificity towards clinically relevant pathologies it has evolved to a reference standard which is in large parts supported by its straightforward applicability and widespread availability.

Improvements in MR hard- and software technology over the last 10–15 years

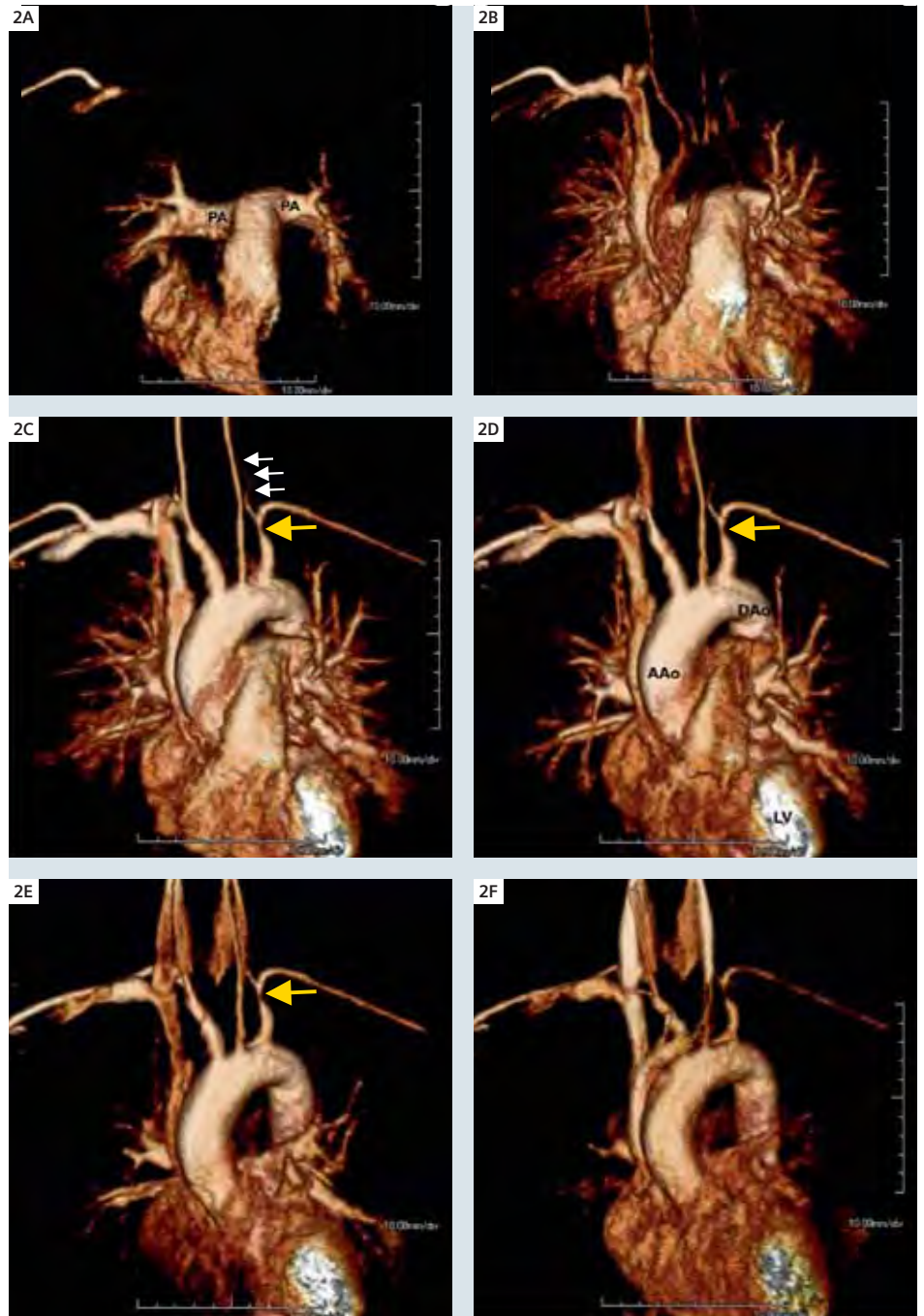
have provided image sampling strategies such as parallel imaging [2], view sharing [3, 4], and partial Fourier transform which are beneficial for magnetic resonance (MR) image acquisition. As correct bolus timing and short sequences due to the limited breathhold capabilities of individual patients are prerequisites to ce-MRA which is based on fast T1-weighted imaging, ce-MRA benefits largely from the combination of modern image acceleration methods to fast acquisition schemes. Comprehensively added to standard gradient echo sequences, improvements in

temporal and/or spatial resolution can be reached. Consequently, if acquisition time and spatial resolution are kept to constant values, the temporal updated rate can be increased and allows for dynamic angiographic imaging. Dynamic or rather time-resolved contrast-enhanced 3D MR-angiography (tr-ce-MRA) is easy to use in clinical routine since no additional bolus timing and time-consuming sequence adjustments are necessary. In addition, tr-ce-MRA techniques provide an excellent separation between arteries and veins. In addition, “dynamic”

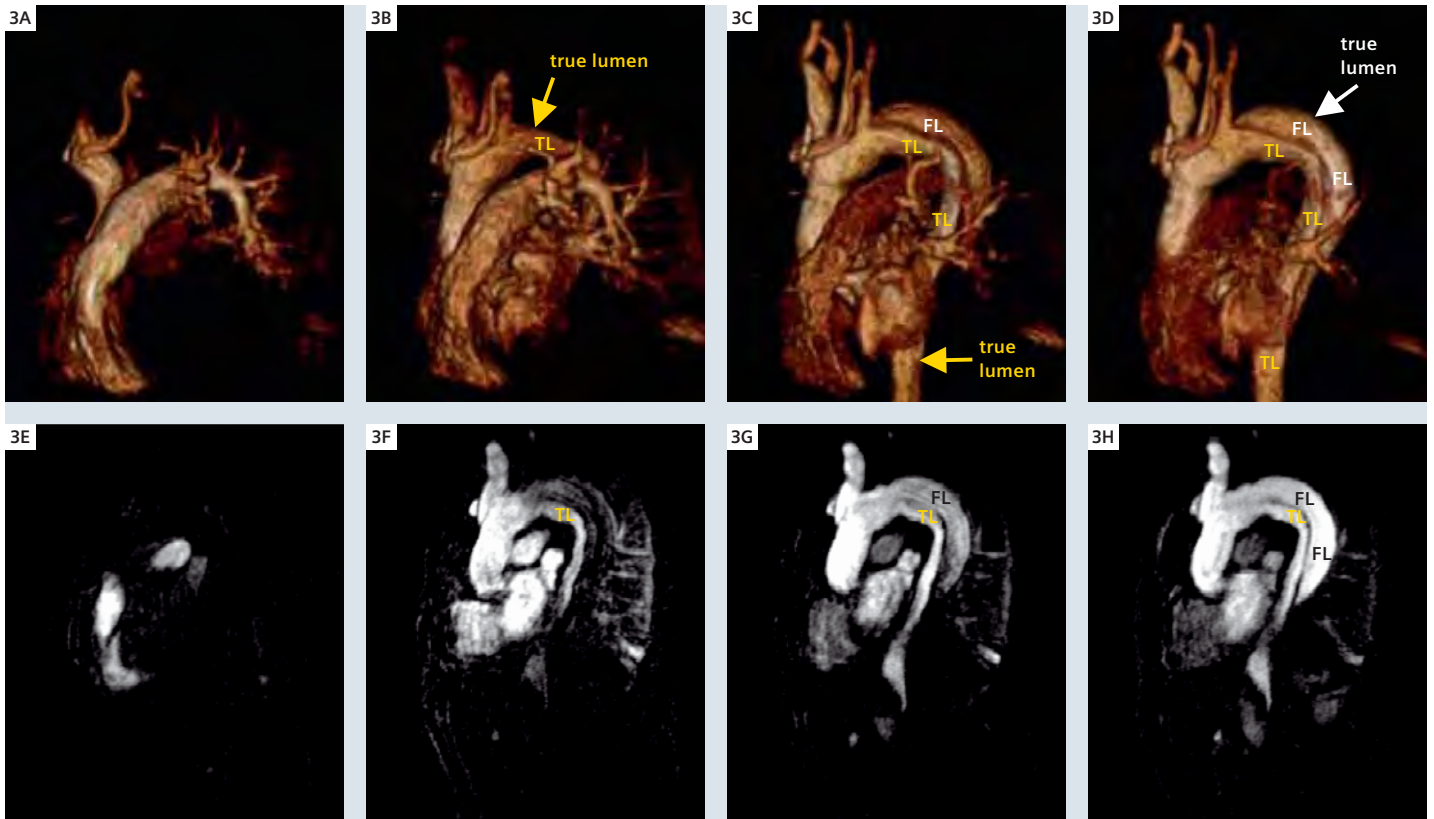


1 Large FoV time-resolved ce-MRA in craniocervical imaging provides information on arterial vasculature as well as venous filling in this patient with suspected thrombosis of the left jugular veins which was excluded. Also, additional information about other vascular territories is available, e.g., arterial filling of the left and right carotid arteries and the circle of Willis.

information about contrast agent distribution over time can be gathered “for free” (Fig. 1). This can be appreciated as the reason why this technique is constantly gaining influence in daily routine especially in imaging of the thoracic vasculature. In thoracic MR-angiography, a good separation of arteries and veins is crucial to diagnosis especially in initial or follow-up examinations of congenital cardiovascular diseases. Although the currently achievable temporal update rates in the order of seconds do not permit true sub-second hemodynamic analyses which are at still subject to multidimensional phase contrast imaging, the clinical applications of tr-ce-MRA are widespread and focus on the pulmonary vasculature [5], thoracic and cerebral vessels. Applications include clinical questions such as pulmonary embolism, arterio-venous malformations and the vascular anatomy. Additionally, the dynamics of contrast material distribution can be used e.g. for pulmonary perfusion studies [6], in search of arterio-venous malformations, shunts or steal phenomena in high-grade stenoses (Fig. 2). Further, it can aid the diagnosis and facilitate the discrimination of true and false lumen in dissection (Fig. 3). Time-resolved sampling schemes such as dynamic projection angiographies and 3-dimensional (3D) sampling schemes have been presented as early as 1996 for routine scanning at 1.5 Tesla [7]. The more recent introduction of modern high-field scanners promises a further gain in signal-to-noise ratio (SNR). Especially in fast T1-based contrast-enhanced ce-MRA this can be exploited as the decrease of T1 relaxation times and thus enhanced T1 shortening effect of (Gd-) gadolinium-based-contrast agents enables for preservation of SNR despite shorter acquisition periods.



2 Volume rendered time-resolved MR-angiography underlines the quality of images which can be reconstructed easily in 3D. Furthermore, this patient with a relevant left sided stenosis of the proximal subclavian artery (yellow arrow) shows instant filling of the left vertebral artery indicating that a subclavian steal phenomenon can be ruled out (white arrows).



3 Representative images from time-resolved large FoV MRA in a patient with Type-A-dissection after surgical repair of the ascending aorta. Next to the clear delineation and diagnostic capability with respect to the exclusion of local insufficiencies or aneurysms, true and false lumen of the dissection can clearly be differentiated by their diverse temporal contrast behavior.

We provide an overview of the technique by focussing on large field-of-view (FoV) applications. These are of interest to clinicians since a large number of routine protocol settings depend on the administration of contrast material but do not focus on the first-pass imaging characteristics. By adding a single sequence in the order of 1 minute scan time, an additional large FoV angiography can be gained for free at virtually no cost for the patient and the diagnosing physician.

How does it work?

Image acquisition is based on a standard angiography technique i.e., rf-spoiled 3D gradient echo sequence. In order to permit data acquisition with an acceptable spatial resolution as well as a temporal update rate in the order of 2.0–3.5 seconds, several image acceleration proce-

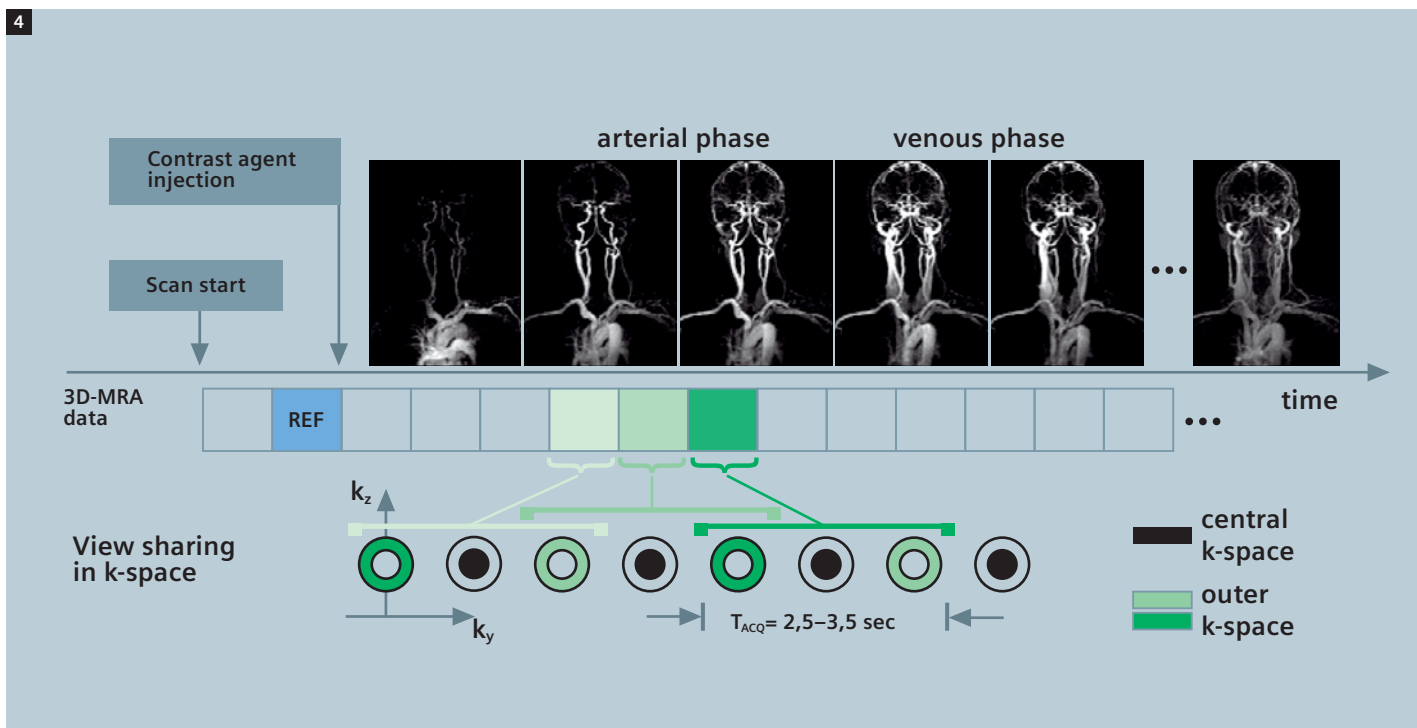
dures are combined to generate a useful time-resolved 3D ce-MRA protocol for neurovascular imaging (cranial and cervical vessels) as well as the depiction of the thoracic angiography (thoracic aorta and branching vessels).

First, parallel imaging (k-space based GRAPPA reconstruction [2]) with an acceleration factor of up to four along the phase encoding direction is employed. In addition, partial Fourier acquisition along the phase and slice encoding direction (for both, partial Fourier factor = 6/8) permits a further reduction of the scan time needed for the acquisition of an entire 3D data volume. Further, view sharing strategies along the temporal domain (such as *syngo* TWIST or TREAT imaging, see also figure 4) based on elliptical centric view ordering, double update rate of central k-space and sharing of outer k-space regions is added

to the imaging protocol [3, 8]. As a result, the effective temporal resolution can <be improved by a factor of 1/3 without compromising the spatial resolution of the individual 3D data volumes [9].

How do we perform time-resolved ce-MRA

Since time-resolved ce-MRA at 3T is fast and easy to perform, it can easily be attached to virtually any contrast enhanced MR imaging protocol in which vascular pathologies are of interest. Thoracic MRA is routinely performed using a standard 8-channel or 12-channel phased-array surface coil. Sagittal oblique or coronal data volumes can be used likewise dependent on the individual patient's anatomy. A dedicated 8-channel phased-array neurovascular coil or a combination of standard Tim Head and Neck Matrix coils can be



4 Data acquisition and image acceleration strategies for time-resolved ce-MRA. Following the scan start, contrast agent is administered after the acquisition of two precontrast 3D data sets. Subsequently acquired 3D MRA data sets depict the dynamics of the passage of the contrast agent bolus as illustrated in the time series of maximum intensity projections reflecting arterial and venous phases of the contrast agent distribution within the vascular system. The effective update rate of the MRA data is increased using temporal view sharing in the k_y - k_z space as shown for three successive time frames (gray shaded squares). Background subtraction was performed using the pre-contrast data set indicated by REF.

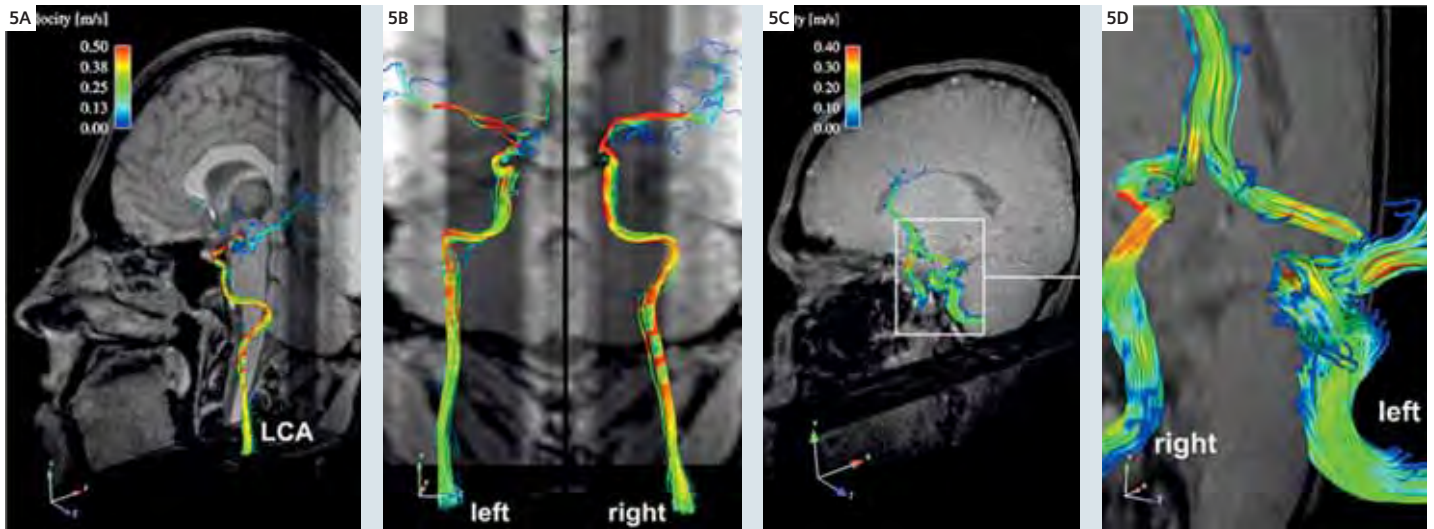
Table 1: Typical scan protocol parameters for large FoV time-resolved ce-MRA

Application	TE / TR [ms]	FoV [mm] (read/phase)	Matrix (read/phase)	Slices/partitions	Spatial res. [mm] (read/phase/slice)	Flip angle	Parallel imaging
Thoracic MRA	0.8 / 2.0	coronal 400 x 400 sagittal 400 x 300	320 x 160	64	coronal 1.3 x 2.5 x 2.2 sagittal 1.3 x 1.9 x 2.2	15-25	GRAPPA accel. factor = 4 24 ref. lines
Cranio-cervical MRA	1.0 / 2.3	coronal 400 x 320	384 x 192	64	1.0 x 1.7 x 2.0	15-25	GRAPPA accel. factor = 4 24 ref. lines

used for craniocervical scans. Typical scan parameters are summarized in table 1. With the resulting imaging protocol 20–30 T1-contrast 3D data volumes are acquired consecutively with a temporal update rate of 2.5-3.3 s. ce-MRA is performed using intravenous gadolinium contrast agent.

As a result of the high temporal update rate no individual assessment of bolus arrival time is needed and contrast agent injection can simply be started after the completion of the acquisition of the first two 3D data volumes (approximately 6 seconds following the initiation of data

acquisition). To avoid transient effects, the second data volume is typically used as a full resolution precontrast data set for background signal elimination through mask subtraction. For a schematic illustration of scan and injection timing see figure 1.



5 True “dynamic” information on blood flow can be gathered by “4D” phase contrast MRI (time-resolved 3D acquisitions with flow encoding for all three spatial directions). Images were acquired on a Siemens MAGNETOM Trio and reveal blood-flow characteristics directly acquired in the extra- and intracranial carotid arteries. Flow velocities and directions are directly measured and displayed color-coded with respect to the actual flow velocities. Note that no simulation of the in-vivo data is necessary.

Conclusion

Time-resolved 3D contrast-enhanced MR-angiography with imaging acceleration along both the spatial encoding direction and temporal domain offers a sound tool to clinicians for everyday routine. Its major advantage derives from the easy to use protocols which allow for MR angiography with every application of contrast agent in approximately 60 seconds of examination time during free breathing. Without the necessity for a bolus timing, MRA

can be performed in demanding situations such as impaired cardiac output, large contrast agent dilution volumes such as in aneurysms and may offer additional information on the detected pathologies. Novel applications exploiting the sensitivity of the MR signal to blood flow are currently emerging that permit further insights into the true hemodynamic conditions of entire vascular systems. Recently reported applications of

such a technique called flow-sensitive 4D MRI have demonstrated its potential for the detailed assessment of the effect of vascular pathologies on local and global time-resolved 3D blood flow (Fig. 5) but are at present limited to research application at a few worldwide centers [10, 11].

*Some of the concepts and information presented in this paper are based on research and are not commercially available in the U.S.

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