MRI on the Move: *syngo* TimCT

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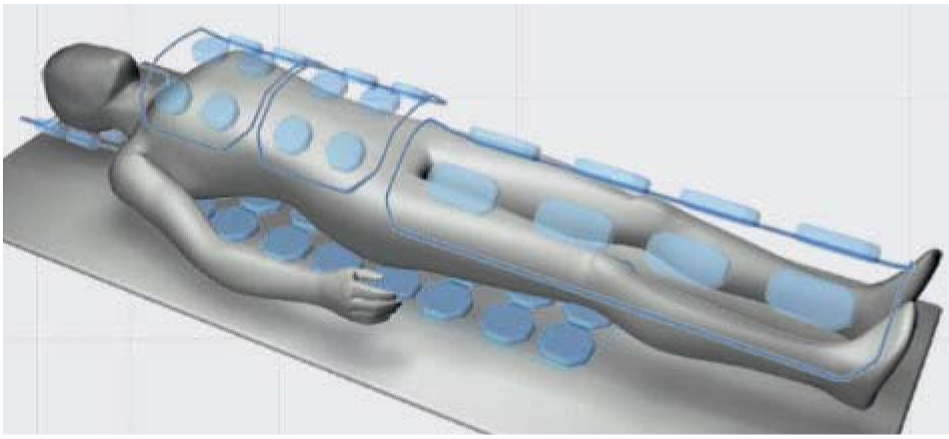
Introduction

The limited field-of-view (FoV) in the cranio-caudal direction inherent to conventional magnetic resonance imaging (MRI) has restricted this imaging modality to a single body region for almost two decades. Many diseases including atherosclerosis and malignant tumors, however, are not limited to a single body region. To fulfill the clinical needs, multi-station protocols using standard hardware [1–4] or commercially available rolling table platforms [5–7] have been developed to extend the FoV in the z-direction. Within the last five years, the combination of fast gradients, rapid automatic table motion and the Tim (Total imaging matrix) radiofrequency (RF) receiver coil technology has even opened the possibility for whole-body MRI without sacrificing signal-to-noise ratio (SNR) or spatial resolution.

These technical developments were the prerequisites to render MR angiography (MRA) one of the most exciting success stories in diagnostic radiology. Bolus-chase techniques employing multi-station table motion allow for the stepwise assessment of different vascular territories within a single examination. Although various multi-station approaches have shown to be effective, these protocols have inherent limitations: in order to cover extended anatomy with high image resolution and to stay within the arterial time window to avoid venous overlay, scan time must be as short as possible. Repositioning of the table between discrete stations reduces the scan time efficiency due to interruption of data acquisition during this process. Additionally, gradient nonlinearities at the edges of individual fields-of-view have to be taken into account.

Most of these limitations have been eliminated by the introduction of the concept of continuously moving table data acquisitions providing seamless volume coverage and optimized scan time efficiency [8]. Since its application to 3D contrast-enhanced MR angiography of the peripheral arteries, several different acquisition and reconstruction methods for MR angiography during continuous table movement have been developed [8, 9]. In all these studies, the feasibility of such "move-during-scan" 3D MRA techniques has been demonstrated using the body radiofrequency (RF) coil for signal reception. The recent combination of the continuously moving table acquisition with full-body surface RF receiver coil coverage provided by the Tim Matrix coil technology allows exploring the full diagnostic potential of this technique [10]. The newest fully integrated implementation *syngo* TimCT (Continuous Table) reflects a revolutionary approach to MRI: motion during scanning, which was considered to be one of the major obstacles limiting the use of MR scanning, is used to extend coverage. TimCT provides seamless volume coverage and optimized scan time efficiency and is fully integrated into the Siemens system architecture. The first application



[Figure 1] *Schematic of Tim phased-array Matrix coils used for peripheral MRA with the syngo TimCT technique. For peripheral MRA the patient lies on the build-in 24-channel Spine Matrix coil and is covered by two 6-element Body Matrix coils as well as by the 8-element Peripheral Angiography Matrix coil. This receiver coil setup ensures optimized signal detection and thus high signal-to-noise (SNR) over the target imaging region and additionally allows for the use of parallel imaging.*

syngo TimCT Angiography is now available and will change the way to perform MRA examinations. Furthermore, techniques to collect stacks of axial 2D slices with different image contrasts during continuous table movement are currently under development. The TimCT technique thus has the potential to further expand the role of MRI with all conceivable imaging applications that exceed the constraints of conventional fields-of-view.

Peripheral MRA workflow: Multi-station vs. *syngo* TimCT

Both peripheral MRA techniques – multi-station as well as TimCT – build on identical hardware prerequisites: full body coverage with dedicated multi-element phased-array surface coils (Tim – Total imaging matrix), connecting to a large number (32) of individual RF receiver channels, in combination with a long distance range of automatic table movement. For peripheral MRA the patient lies on the built-in 24-channel Spine Matrix coil and for anterior signal detection is covered by two 6-element Body Matrix coils as well as by the 8-element Peripheral Angiography Matrix coil (Fig. 1). The Tim surface RF coils ensure optimized signal detection and thus high SNR over the target imaging region and additionally allow for the use of parallel imaging with GRAPPA (Generalized Autocalibrating Partially Parallel Acquisitions) [11] to either speed up data acquisition time or to increase spatial resolution instead.

Multi-station MRA

While acquisition of 3D peripheral MRA data sets with the conventional multi-station MRA protocol requires a relative large number of examination steps, the continuously moving table technique TimCT considerably eases the workflow (Fig. 2). Multi-station MRA of the peripheral arteries commences with centering the patient with the feet in the isocenter of the magnet (step 1), followed by the acquisition of TrueFISP localizers in three individual stations covering the pelvis, upper legs, and lower legs (steps 2–4). This is also associated with table movement between the stations while data acquisition is paused. Acquisition of TrueFISP localizers is subsequently followed by planning and acquisition of native scans for the 3D FLASH (Fast Low-Angle Shot) MRA in coronal orientation on the individual localizers (steps 5–7). Following injection of the contrast agent (step 8), the CareBolus technique (step 9) provides information upon arrival of the contrast bolus in the target vascular region. Once the arriving contrast bolus enhances the signal in the images of the CareBolus sequence, data acquisition for the contrast-enhanced 3D FLASH MRA in the pelvis station is initiated (step 10). Data acquisition is being paused while the patient table moves to the upper leg station (step 11) and then – in another step – further down to the lower leg station (step 12).

Multi-station protocol

1	Position 230mm above feet
2	I_trufisp_feet
3	II_trufisp_legs
4	III_trufisp_abdomen
5	I_fl3d-cor_feet_pre
6	II_fl3d-cor_legs_pre
7	III_fl3d-cor_abdomen_pre
8	inject gad
9	III_care_bolus_cor
10	III_fl3d-cor_abdomen_post
11	II_fl3d-cor_legs_post
12	I_fl3d-cor_feet_post

***syngo* TimCT protocol**

1	Fastview
2	TestBolus_tra
3	Vesselscout
4	Angio_pre_1300mm
5	inject
6	Angio_post_1300mm

[Figure 2] *Workflow of a conventional three-step multi-station peripheral MRA protocol in comparison to the continuously moving table peripheral MRA protocol with syngo TimCT. While the multi-station protocol requires 12 steps to perform peripheral MRA, the continuously moving table protocol can be streamlined down to 6 steps.*

[Figure 3] *syngo TimCT FastView and planning of the TestBolus. The FastView sequence is based on a fast gradient echo sequence with fixed sequence parameters that runs without further sequence adjustments. The acquisition scan plane is transversal. Subsequent to data acquisition coronal and sagittal slices are automatically reformatted online. These reformats provide a gross overview of the patient's anatomy and serve as localizers to plan the transversal plane of the TestBolus sequence (yellow frame).*

MRA with TimCT – How to set things to move

The TimCT protocol for performing peripheral MRA consists of 6 steps only (Fig. 2). Image planning on large FoV body localizers and vessel scouts streamlines the workflow, thus facilitating the setup of large FoV examinations. The TimCT peripheral MRA examination starts with the acquisition of a FastView localizer (step 1):

[1] *syngo* TimCT FastView

The FastView sequence is based on a fast 2D gradient echo sequence with fixed sequence parameters and runs without further sequence adjustments. The acquisition scan plane is transversal. The scanning range extends from the head region down to the feet with almost whole-body coverage. Subsequent to data acquisition, large field-of-view (FoV) coronal and sagittal slices are automatically reformatted and displayed online. These reformats provide a gross overview of the patient's anatomy and serve as localizers to plan further examination steps (Fig. 3). Since the FastView sequence uses only low flip angles for spin excitation, this sequence is non-critical with regards to the specific absorption rate (SAR). While the FastView is being acquired, the MRI system automatically detects and displays individual RF coil positions of the Tim Matrix coils with regard to their location on the patient's body. Another feature is that FastView provides all relevant scanner adjustment parameters with feedback to the system while the scan is being acquired.

[2] TestBolus

Contrast bolus timing for peripheral MRA in the TimCT protocol is performed with the TestBolus sequence. This T1-weighted 2D fast gradient echo sequence provides one thick imaging slice that is oriented in the transversal plane and positioned several centimeters above the renal arteries (Fig. 3). The Test-Bolus sequence provides one image per second and runs for 60 seconds. The sequence is started simultaneously with administration of a small contrast agent bolus (e.g. 2 ml). Signal enhancement in the aorta indicates arrival of the contrast bolus in the target vessel. With careful investigation of the TestBolus images, the time interval from contrast injection to contrast arrival in the target vessel can be determined. This contrast bolus travel time has to be considered for proper synchroniszation of the contrast injection with the breath-hold command for the patient, and with the initiation of data acquisition for the 3D FLASH TimCT MRA sequence.

[3] VesselScout

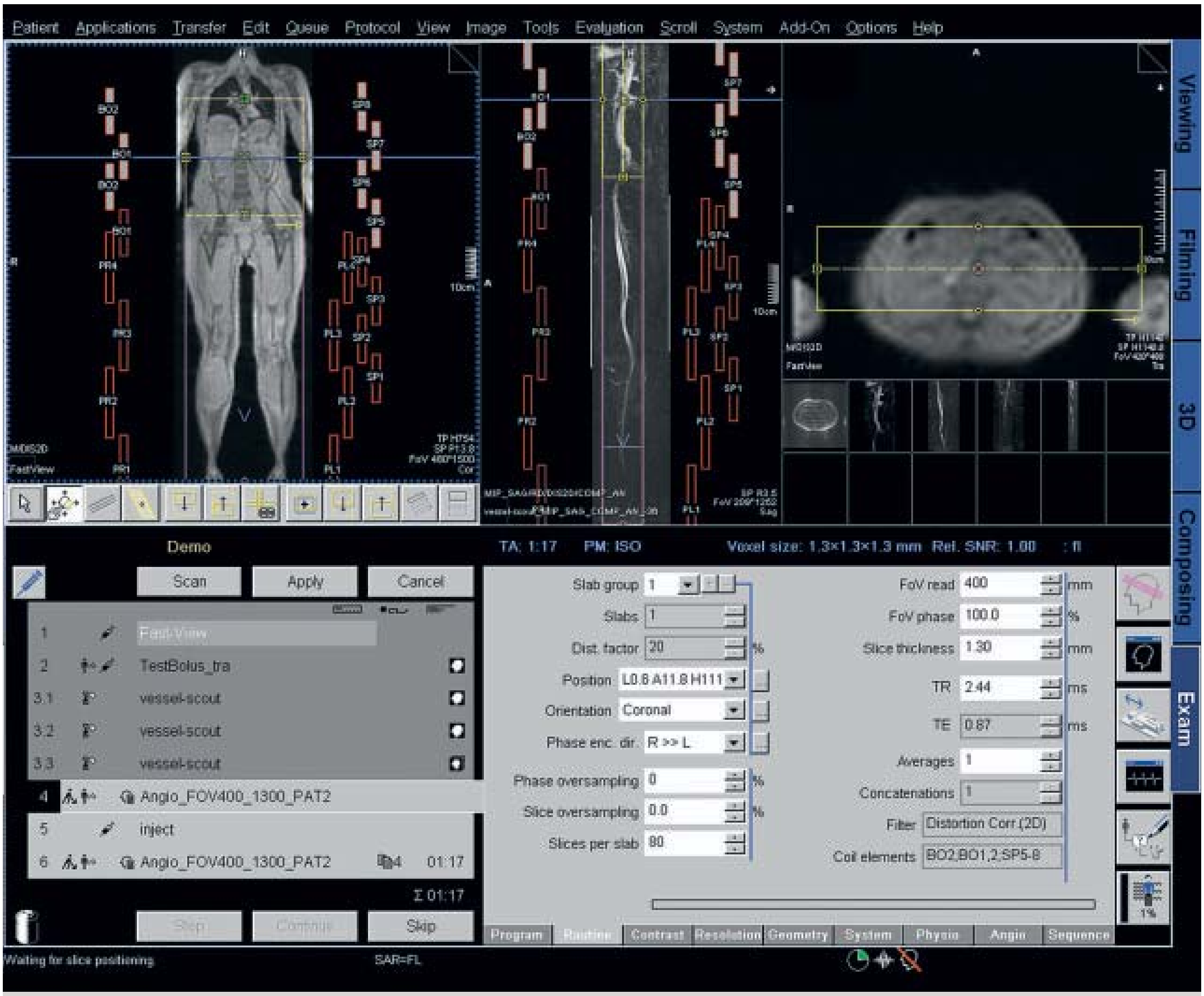
The VesselScout sequence provides a fast comprehensive large FoV overview of the target vessel tree. The VesselScout sequence is based on a fast rephased-dephased gradient echo sequence that generates two echoes per excitation to provide images where signal of static tissue is eliminated while signal from flowing blood is preserved. Planning of the multi-station VesselScout is performed in sagittal orientation on the previously acquired whole-body images provided by the FastView localizer (Fig. 4). Subsequent to data acquisition, the images of this multi-station sequence are composed online and provide a comprehensive large FoV overview of

[Figure 4] *syngo TimCT FastView and planning of the VesselScout. Here the whole-body localizers provided by the FastView sequence serve as a basis to plan the VesselScout sequence. This is a multi-station rephased-dephased localizer in sagittal orientation with inline composing. The rephased-dephased sequence eliminates signal from static tissue and preserves signal from flowing blood thus providing a fast sagittal overview of the entire vessel tree.*

the larger peripheral arteries. This vessel localizer can then be used for further planning of the 3D MRA imaging volumes.

[4] *syngo* TimCT 3D MRA native

Planning of the 3D FLASH MRA imaging volume is performed in coronal orientation on the previously acquired whole-body localizer provided by the FastView sequence as well as on the large FoV target vessel localizer provided by the VesselScout sequence (Fig. 5). Since this is a continuously moving table protocol, the user only has to assure that the MRA volume covers the vessels of interest over the full lengths of the VesselScout and that the imaging range is covered with surface RF coils. No further steps are required. The patient is instructed with a breathing command to inspire and to hold his breath at the beginning of the examination (abdominal region). The TimCT technology here provides data acquisition while the table with the patient is continuously moving through the isocenter of the magnet. During continuous table movement, the MRI scanner among the matrix of Tim RF coils automatically detects the receive coil elements that are inside of the isocenter at a time and "on-the-fly" switches off all coil elements outside of the isocenter. This effectively cuts down the number of active coil elements and thus reduces the amount of acquired data and avoids noise sam-



[Figure 5] *VesselScout and planning of the syngo TimCT 3D FLASH MRA sequence. The coronal view of the FastView localizer and the sagittal view of the Vessel Scout together serve as reference for planning of the coronal slab of the 3D FLASH MRA sequence. Since this is a continuously moving table protocol, the user only has to assure that the MRA volume covers the vessels of interest over the full lengths of the VesselScout. No further planning steps are required.*

[Figure 6] *3D coronal maximum intensity projection (MIP) of the peripheral MRA of a 30-year-old male healthy volunteer acquired with the continuously moving table technique syngo TimCT. The technique here provides a seamless large field-of-view (FoV) 3D MR angiogram covering the suprarenal aorta down to the peripheral arteries with high image quality.*

pling of RF coils that do not contribute to the imaging signal. Immediately after finishing the data acquisition, online image reconstruction is being performed and seamless large-FoV native images of the 3D imaging volume are being displayed. These non-contrast native images are the basis for post-contrast image subtraction.

[5] Contrast injection

For the peripheral MRA TimCT protocol, contrast agent was administered with a biphasic contrast injection scheme using an automatic contrast injector. The first third of the volume was injected with a flow rate of 0.8 ml/sec. The remaining two thirds of the contrast volume were injected with a flow rate of 0.5 ml/sec followed by a saline flush of 20 ml at a flow rate of 1.0 ml/sec.*

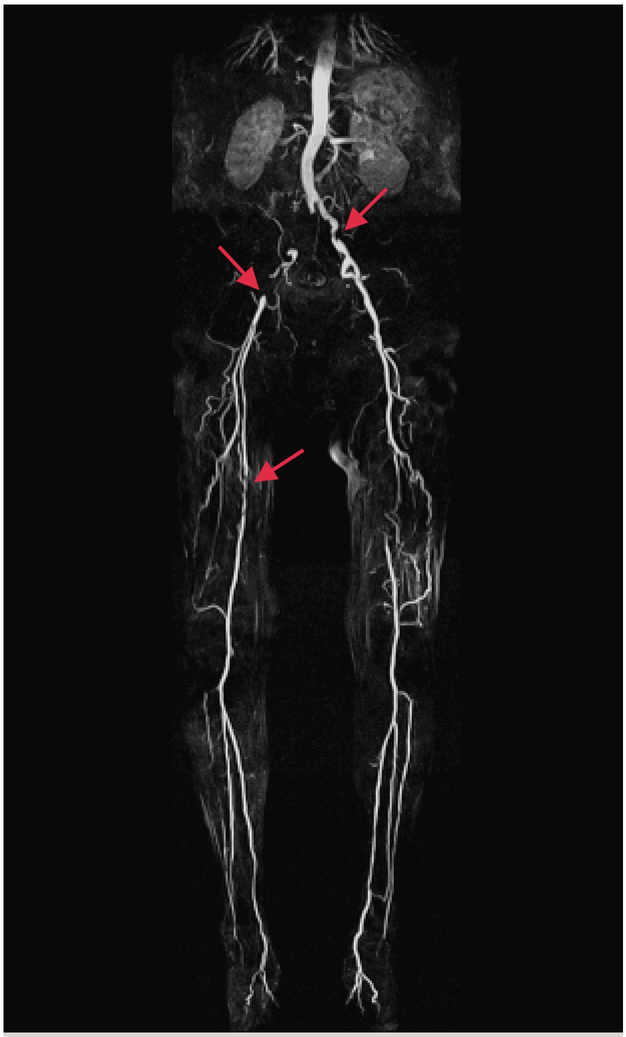
[6] 3D MRA contrast

Following contrast injection, in this last step of the TimCT angiographic examination of the peripheral arteries, the 3D FLASH MRA sequence with continuously moving table technique is rescanned with identical imaging parameters as described for the 3D FLASH native scan (see step 4). The patient again is instructed with a breathing command to hold his breath while the abdominal body region initially is in the isocenter. The patient table continuously moves through the isocenter of the magnet as the contrast-bolus travels continuously through the peripheral arteries of the patient. This finally results in a coronal oriented seamless large FoV 3D MRA data set covering the arterial contrast phase of the abdominal aorta from the renal arteries over the peripheral arteries down to the feet. The images of the previously acquired native 3D FLASH scan are automatically subtracted from the contrast images, resulting in angiographic images with subtracted background signal. The resulting background-subtracted source images are reconstructed as large FoV coronal displays of the target vessels that can be post-processed as comprehensive maximum intensity projections (MIP) displays of the complete vessel tree in a single step (Fig. 6). Imaging parameters for the large FoV peripheral MRA TimCT protocol were: 3D FLASH coronal, TR/TE 2.44/0.87 ms, flip angle 25°, bandwidth 1420 Hz/pixel, FoV 400 x 1300 mm, matrix 320 x 1380, slab width 115 mm. Parallel imaging with GRAPPA (acceleration factor of 2, 24 reference lines) resulted in a large FoV 3D MRA data set with an isotropic spatial resolution of 1.3 x 1.3 x 1.3 mm^3 that was acquired within 77 seconds.

Moving patients with TimCT: First clinical experience

Direct comparison of conventional three-step multi-station peripheral MRA to the first clinical application of the continuously moving table *syngo* TimCT technique in patients with peripheral arterial occlusive disease (PAOD) revealed excellent image correlation of both techniques (Fig. 7). Both techniques provided comparable image quality. Image interpretation and vessel assessment on TimCT images was facilitated due to the lack of discontinuity artifacts. However, due to higher spatial resolution of the two lower stations using the standard multi-station protocol, small intravascular arterial vessels appeared slightly crisper in this protocol. The time for data reconstruction was comparable for both protocols (2 min). From a user's point of view, the streamlined workflow of the TimCT protocol considerably facilitated planning of the large FoV 3D MRA data slab that in the TimCT protocol is performed straightforward on two comprehensive data sets (FastView and VesselScout) while three individual 3D image slabs have to be positioned and oriented in the conventional multi-station protocol.

[Figure 7] *3D coronal maximum intensity projections (MIP) of the peripheral conventional three-step multi-station MRA protocol in comparison to the continuously moving table protocol with syngo TimCT acquired on a 60-year-old male patient with peripheral arterial occlusive disease (PAOD). Note that the multi-station protocol acquires multiple slightly overlapping fields-of-view (FoV) while the continuously moving table protocol provides one seamless large FoV with full anatomic coverage that is not hampered by any discontinuity artifacts.*



[Figure 8] *Continuously acquired 3D MRA of the peripheral vasculature in a 63-year-old male patient with peripheral arterial occlusive disease (PAOD) (Rutherford grade II Category 4). Note multiple stenoses and occlusions (arrows), especially in the pelvic and upper leg region.*

Conclusion

The *syngo* TimCT technique provides high-quality seamless large field-of-view MR images for virtually all imaging applications that exceed the constraints of conventional FoVs. In contrast to multi-station techniques, boundary artifacts that might appear at the edges between two adjacent FoVs are completely eliminated. The technique significantly reduces the number of examination steps thus streamlining the workflow to perform comprehensive large FoV examinations. Peripheral MRA – as demonstrated here – is the first among a large palette of other MR imaging applications that exceed the constraints of conventional FoVs. Further extension to whole-body MRA as well as whole-body metastasis screening and staging in oncologic patients will potentially benefit from the *syngo* TimCT technique as well. The TimCT technique furthermore holds potential for further expanding the role of open short-bore MRI systems – like the MAGNETOM Espree – that inherently provide limited FoVs in the longitudinal direction. Get ready to move!

*Works In Progress – The information about this product is preliminary. The product is under development. It is not commercially available in the US and its future availability cannot be assured.

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Harald H. Quick, Ph.D. (left) and Jörg Barkhausen, M.D. (right).

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