MR angiography of peripheral arterial disease of the distal legs: is time resolved MRA (TRICKS) necessary?

E Archambault (1), P Gouny (2), T Hébert (1), N Salley (2), E Nowak (3) and M Nonent (1,4)

Résumé

Angiographie par Résonance Magnétique dans l’artériopathie distale des membres inférieurs : peut-on se passer d’une séquence multiphase (TRICKS) ?

J Radiol 2008;89:863-71


Patients et méthodes. Quarante patients (30 % diabétiques) présentant une artériopathie oblitérante des membres inférieurs (AOMI) (87,5 % en ischémie permanente), ont bénéficié d’un bilan comportant une ARM standard et une séquence TRICKS centrée sur les artères distales. Cinq segments artériaux par jambe étant définis, une analyse comparative de 395 segments artériaux a été réalisée (un patient amputé). Deux relecteurs ont évalué la qualité d’analyse des segments artériaux, la présence d’un retour veineux gênant et le degré de sténose par segment. La concordance interobservateurs pour l’estimation du degré de sténose a été calculée.

Résultats. La séquence TRICKS augmente le nombre d’artères analysables en ARM (analyse bonne ou excellente dans 63,03 %-66,32 % des segments artériaux versus 41,51 %-47,08 % pour l’ARM standard). Elle diminue les superpositions veineuses gênantes (gain de 25,57 % à 27,60 %). La concordance interobservateurs pour l’estimation du degré de sténose est meilleure pour le TRICKS que pour l’ARM standard (kappa 0,85 vs 0,69).

Conclusion. La séquence TRICKS peut être recommandée en complément de l’ARM standard 3 paliers pour l’évaluation préthérapeutique des artères distales chez les patients présentant une AOMI, notamment en ischémie permanente avec douleurs de décubitus et/ou troubles trophiques.


Abstract

Purpose. To demonstrate the added diagnostic value of time-resolved imaging of contrast kinetics (TRICKS) in the evaluation of lower limb arteries compared to standard 3 level MRA with stepping table method.

Patients and methods. Forty patients (30% diabetics) with lower extremity peripheral arterial disease (87.5% with chronic ischemia) underwent standard contrast MRA including TRICKS of the distal arteries. Five arterial segments were defined per leg, and 395 arterial segments were compared (one patient with amputation). Two reviewers evaluated the quality of arterial imaging, presence of venous return and degree of stenosis per segment. The degree of interobserver agreement for arterial stenosis measurement was calculated.

Results. More arterial segments could be analyzed on the TRICKS sequence (good or excellent analysis in 63.03%-66.32% of arterial segments compared to 41.51%-47.08% on routine MRA). There was less venous contamination on TRICKS images (25.57% to 27.60% gain). The degree of interobserver agreement was superior with TRICKS compared to standard MRA (kappa 0.85 vs 0.69).

Conclusion. The TRICKS sequence can be added to standard MRA for pre-therapeutic evaluation of distal arteries in patients with peripheral arterial disease, especially with chronic ischemic with rest pain and/or trophic changes.

Key words: Magnetic resonance angiography. Multiphase. Atherosclerosis. Arteritis.

To cite the present paper, use exclusively the following reference. Archambault E, Gouny P, Hébert T, Salley N, Nowak E, Nonent M. Angiographie par Résonance Magnétique dans l’artériopathie distale des membres inférieurs : peut-on se passer d’une séquence multiphase (TRICKS) ?

(1) Service de Radiologie et Imagerie Médicale, Hôpital de la Cavale Blanche, CHU Brest, boulevard Tanguy Prigent, 29609 Brest Cedex.
(2) Service de Chirurgie Cardiaque Thérapeutique et Vasculaire, Hôpital de la Cavale Blanche, CHU Brest, boulevard Tanguy Prigent, 29609 Brest Cedex.
(3) Centre d’Investigation Clinique, INSERM U952, Hôpital de la Cavale Blanche, CHU Brest, boulevard Tanguy Prigent, 29609 Brest Cedex.
(4) Groupe d’Étude de la Thrombose de Bretagne Occidentale (GETBO), EA 3878, Université de Bretagne Occidentale (UBO), Brest.

Correspondence: M Nonent
E-mail: michel.nonent@chu-brest.fr
lies (especially below knee), and arteries of the calf and foot (2). Diagnostic angiography is seldom performed and advances with computed-tomography angiography (CTA) (3) and magnetic resonance angiography (MRA) now allow complete non-invasive workup of patients.

MRA has three main advantages: calcifications do not interfere with the interpretation of images, may be performed in patients with renal failure, and ease of image post-processing. Arterial calcifications are not visible on MRA, allowing for easier quantification of calcified stenoses or arterial diameter in patients with diffuse arterial wall calcifications. However, the lack of demonstration of calcifications may be a pitfall since knowledge of their presence and location may have an impact on the selection of a site for vascular anastomosis at the time of surgical bypass or help predict the likelihood of success of angioplasty. The advantages of gadolinium enhanced MRA in patients with renal failure are lessened by recent reports of nephrogenic systemic fibrosis (NSF) in patients with severe renal failure, mainly in association with gadodiamide (4).

The diagnostic accuracy of gadolinium enhanced MRA has been established by several publications and meta-analyses (5-7). The sensitivity and specificity of MRA are good and it has been demonstrated that MRA was able to detect more arterial segments than catheter angiography (8).

The routine “3 station” step table gadolinium enhanced MRA technique presents two problems, often interrelated: detection of distal arterial segments and venous contamination at the calf and foot level, requiring an improvement in both temporal and spatial resolution. Multiphase acquisitions, such as 3D TRICKS (Time Resolved Imaging of Contrast KineticS), provide a potential solution to both problems and allow near real time visualization of contrast arrival in the arteries and veins (9).

The purpose of this paper is to determine if the TRICKS sequence is useful in the pretherapeutic workup of PAD. The indications for MRA were consistent with routinely approved indications in our department: patients with rest ischemia with pain and/or trophic skin changes and/or severe renal failure (GFR < 30 ml/min) with contraindication to the use of iodinated contrast material. Thirty-five patients had rest pain and/or trophic skin changes and five patients had claudication. One patient had unilateral leg amputation. Twelve patients were diabetics. The mean age was 74.3 years and the M/F sex ratio was 1.5 (24 males, 16 females). No other pretherapeutic imaging modality (catheter angiography, CTA) was used.

### Materials and methods

#### Patients

Forty consecutive patients underwent MRA evaluation of the lower extremities as part of the pretherapeutic workup of PAD. The indications for MRA were consistent with routinely approved indications in our department: patients with rest ischemia with pain and/or trophic skin changes and/or severe renal failure (GFR < 30 ml/min) with contraindication to the use of iodinated contrast material. Thirty-five patients had rest pain and/or trophic skin changes and five patients had claudication. One patient had unilateral leg amputation. Twelve patients were diabetics. The mean age was 74.3 years and the M/F sex ratio was 1.5 (24 males, 16 females). No other pretherapeutic imaging modality (catheter angiography, CTA) was used.

#### Acquisition protocol for 3 station MRA

Gradient-echo localized sequences were obtained in all three planes to assist in positioning the acquisition volumes. The acquisition was performed using 3 stations (table I), aorto-iliac, femoro-popliteal, and lower leg, with automated table motion. The field of view (FOV) was 46 cm for each station. A 3D gradient-echo acquisition was obtained over a coronal rectangular FOV using the body coil for the upper and middle stations and a phased-array torso coil or dedicated HD lower leg array for the lower station. The upper and middle stations were obtained using centric acquisitions, each of 16 seconds duration. The lower station was obtained using an elliptical centric acquisition with longer acquisition time (58 seconds), providing improved spatial resolution. Table motion between each station took 4 seconds. A noncontrast acquisition was first obtained at each station for image sub-

### Table I

<table>
<thead>
<tr>
<th>Acquisition parameters.</th>
<th>TRICKS</th>
<th>3 station MRA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st station</td>
<td>2nd station</td>
</tr>
<tr>
<td><strong>Coil</strong></td>
<td>HD Lower Leg</td>
<td>« body »</td>
</tr>
<tr>
<td><strong>Array</strong></td>
<td>HD Lower Leg</td>
<td>HD Lower Leg</td>
</tr>
<tr>
<td><strong>FOV</strong></td>
<td>46cm</td>
<td>46cm</td>
</tr>
<tr>
<td><strong>Number of excitation</strong></td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td><strong>Matrix</strong></td>
<td>512x320</td>
<td>320x160</td>
</tr>
<tr>
<td><strong>Slice thickness</strong></td>
<td>1.6mm</td>
<td>4mm*</td>
</tr>
<tr>
<td><strong>Overlap</strong></td>
<td>Contiguous</td>
<td>3mm</td>
</tr>
<tr>
<td><strong>Number of slices</strong></td>
<td>80 (per phase)</td>
<td>140</td>
</tr>
<tr>
<td><strong>TE</strong></td>
<td>1.6ms</td>
<td>1.2ms</td>
</tr>
<tr>
<td><strong>TR</strong></td>
<td>4.4ms</td>
<td>3.5ms</td>
</tr>
<tr>
<td><strong>Flip angle</strong></td>
<td>35°</td>
<td>35°</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>100KHz</td>
<td>83KHz</td>
</tr>
<tr>
<td><strong>Interpolation</strong></td>
<td>No</td>
<td>ZIP 512/ZIP 4</td>
</tr>
<tr>
<td><strong>Sampling</strong></td>
<td>Elliptical centric</td>
<td>centric</td>
</tr>
<tr>
<td><strong>Acquisition time</strong></td>
<td>2 min 54 s</td>
<td>16 s</td>
</tr>
</tbody>
</table>

* prior to zero fill interpolation.
traction. A zero fill interpolation in the Z axis was used. A biphasic injection of gadolinium contrast material and saline was performed using a power injector (Medrad). The acquisition was triggered upon fluoroscopic detection of contrast arrival. MIP reconstructions (12 projections) were generated for each station on an Advantage Windows workstation; image pasting was used to create full length MRA images from aorta to feet.

Acquisition protocol for TRICKS MRA

The TRICKS sequence (table I) is a gadolinium enhanced 3D MRA sequence with multiple phases, each containing 80 native images. The FOV extended from the popliteal fossa to the ankle allowing visualization of the dorsalis pedis and plantar arteries. A mask was first acquired for image subtraction. The acquisition of the mask as part of the sequence as opposed to a separate acquisition, such as with conventional MRA, reduces motion artifacts at the time of subtraction.

K space was divided concentrically into 4 subvolumes A, B, C, D in the slice encoding and phase encoding directions (fig. 1), with more frequent refresh at the center of k space (image contrast), and retrospective interpolation of data allowing reconstruction of 8 phases depicting the progression of contrast from arteries to veins.

The temporal resolution corresponding to the frequency of acquisition of the Fourier space was 10.4 seconds (temporal resolution = TR x Nz x Ny/Nr; TR: repetition time, Nz: number of slices, Ny: number of phase encoding steps, and Nr: number of subvolumes or 4 in this case). Mask acquisition time was 42 seconds, and the entire sequence duration was 2 minutes and 54 seconds. For generation of the different phases of imaging (temporal interpolation), data acquired in subvolumes A1, B2, C3 and D4 at the beginning of the sequence, prior to the arrival of the contrast bolus, were used to generate the mask. To reconstruct any given phase Tx, native data acquired at the phase Tx (A, B, C, D) were associated to the closest pairs of the concentric subvolumes (for example phase 7 is reconstructed using A7, B6 and B12, C3, and C8, D4 and D10), and the mask is then automatically subtracted (fig. 2). The software then generates volumetric images of the different phases (8 phases with 80 images each) with coronal MIP images corresponding to the sum of the native images for each phase providing an angiographic-like dynamic depiction of contrast progression. Each of the phases may then be post-processed to generate MIP images with additional projections.

Injection protocol

Gadobenate dimeglumine (MultiHance®) was used. Two injections were required, one for the standard MRA and another for the TRICKS MRA. For the standard 3 station MRA, a bi-phasic injection was used: 12 ml at 1.7 ml/sec then 20 ml at 0.7 ml/sec followed by 30 ml saline chase at 0.7 ml/sec. For the TRICKS sequence, 12 ml of MultiHance® was injected at 0.5 ml/sec followed by a 20 ml saline chase at 0.5 ml/sec. For the TRICKS sequence, precise synchronization between acquisition and contrast bolus arrival was not required. In order to ensure that the mask was acquired prior to the arrival of contrast, the injection was started 30 seconds after the sequence was started.

As a general rule, the bolus duration should be as long as the temporal window of the acquisition.
Review of examinations

All examinations were retrospectively reviewed by two radiologists, a resident (reviewer 1) and an attending with over 15 years of experience in vascular radiology (reviewer 2). The images were reviewed on an independent workstation (Advantage Windows GE). Both native and MIP images were reviewed. The 3-station MRAs and TRICKS MRAs were reviewed separately, in a random order, at a few weeks interval. The reviewers were blinded to clinical data. The lower leg vessels were divided into 5 segments: popliteal artery, anterior tibial artery, tibio-peroneal trunk, posterior tibial artery and peroneal artery. Three items were specifically evaluated: quality of the visualization of arterial segments graded 0 (non-interpretable), 1 (moderate), 2 (good), 3 (excellent); degree of venous contamination graded 0 (significant), 1 (absent or not interfering with interpretation); estimation of degree of stenosis graded 0 (no stenosis or stenosis < 50%), 1 (50-75% stenosis), 2 (stenosis > 75%), 3 (occlusion). When more than one area of stenosis was present on a given segment, the most severe stenosis was recorded. In order to ensure that both reviewers were estimating the same area of stenosis, the area of most severe stenosis was recorded by each reviewer by subdividing each segment in three thirds (upper, middle, and lower). Data were collected in individual folders than inputted into an excel spreadsheet. Interobserver agreement for estimating the degree of stenosis per segment was calculated using the R software version 2.4.1 (R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org).

Results

Quality of visualization of arterial segments

The quality of visualization of arterial segments (table II) was clearly superior on the TRICKS sequence compared to the standard MRA. With TRICKS imaging, there was 36% improvement for both reviewers for non-interpretable and moderate quality segments; the number of segments graded as good or excellent quality increased by 29% for reviewer 1 and 34% for reviewer 2.

Venous contamination interfering with interpretation

Venous contamination interfering with interpretation was reduced by 25.57% and 27.60% for reviewers 1 and 2 respectively on the TRICKS sequence compared to the standard MRA (table III).

Interobserver agreement for quantification of stenosis per segment

Most patients presented multifocal arterial stenoses. Interobserver agreement for the quantification of stenoses (table IV) was significantly superior with the TRICKS sequence (kappa = 0.85, excellent) compared to the standard MRA (kappa = 0.69, good). The difference was more important at the popliteal (kappa of 0.93 versus 0.65) and tibial (kappa of 0.87 and 0.91 respectively for the anterior and posterior tibial segments on TRICKS versus 0.60 and 0.75 on standard MRA) segments. The difference was less marked for the tibio-peroneal trunk and peroneal artery.

Discussion

Evaluation of distal arteries is mandatory in patients with chronic ischemia, especially diabetics. Standard MRA techniques based on bolus tracking with table motion have limitations with regards to the synchronization of image acquisition with arterial phase of enhancement (10). Our results demonstrate that TRICKS MRA significantly improves the quality of vessel depiction at the lower leg level.
with reduced venous contamination and improved interobserver agreement for quantification of stenosis compared to standard MRA.

Our results are overall consistent with reports from other authors. Hany, in 2001, reported that the number of interpretable arterial segments was clearly superior with TRICKS compared to 3 station MRA. He reported that 100% of segments were interpretable on TRICKS compared to 41.6% for 3 station MRA (11). Nicolas, in 2005, reported that 31% of segments were non-interpretable on TRICKS compared to 19% on standard MRA, while TRICKS was superior in sub-populations of patients with diabetes or venous insufficiency (12). Image quality from venous contamination was reported in up to 30% of cases for 3 station MRA (11, 13). Venous contamination was reported in 50% to 60% of arterial segments on 3 station MRA, but interpretation was impossible in only 16.96% and 26.83% of segments for the attending and resident reviewers respectively. Venous contamination was recorded in 22.78% and 34.43% of segments for the attending and resident reviewers respectively on TRICKS MRA. Venous contamination is due to early venous return, a frequent finding in patients with trophic skin changes or venous insufficiency. In such cases, TRICKS imaging may not produce a sufficient number of pure arterial phase images for optimal evaluation. However, venous contamination interferes less with diagnosis on TRICKS compared to standard MRA, and fewer segments are non-interpretable or of moderate quality on TRICKS (fig. 3 to 6). In our series, the interobserver agreement for TRICKS was excellent (0.85) and significantly superior to the agreement for standard MRA (0.69) with regards to quantification of stenosis. This result is superior to the result recently reported by Andreisek with kappa value of 0.78 for TRICKS and 0.71 for standard MRA (14).

Our results confirm the value of TRICKS MRA for evaluation of lower leg arterial segments. First described in 1996 by Korosec (9), this sequence allows the acquisition of sequential dynamic images due to variable filling of Fourier space with repeated sampling at the center of k-space and temporal interpolation. Because the mask is an inherent part of the sequence, a bolus test injection is not needed and acquisition of a separate mask also is not needed. The accuracy of the TRICKS sequence has been assessed and compared
MR angiography of peripheral arterial disease of the distal legs: is time resolved MRA (TRICKS) necessary?

E Archambault et al.

to catheter angiography in a number of recent publications. Mell reported sensitivity and specificity values of 94% and 92% respectively for quantification of stenosis at the popliteal artery level. For the tibial arteries, the sensitivity was 100% and the specificity was 84%. In this study, arterial access was accurately planned based on preprocedural MRA findings in 29 of 30 patients (15). Swan reported that TRICKS MRA allowed depiction of 27% more patent distal arteries not demonstrated on catheter angiography due to poor filling of peripheral arteries distal to long segmental areas of occlusion (16).

The TRICKS sequence, reconstructed by interpolation, is very sensitive to motion, especially given its long acquisition time (over 4 minutes). Motion artifacts explain at least in part the number of non-interpretable examinations which remain significant in our series, even if lower than for standard MRA. The patients, often in pain, have difficulty remaining still. In order to reduce the risk of motion artifacts, we believe that TRICKS MRA should be acquired first, then followed by multi-station MRA to image the aorto-iliac and femoral stations. This sequence of acquisitions also reduces the risk of residual venous contamination after acquisition of the 3rd station on standard MRA.

The spatial resolution of TRICKS MRA is slightly inferior to the resolution of standard MRA. This pitfall, largely
compensated by the value of the added temporal resolution, may be reduced by the acquisition of sagittal images of the lower leg and foot with improved spatial resolution, at the price of a unilateral acquisition (17). Modifications to the TRICKS sequence have been proposed to improve spatial resolution. PR-TRICKS (projection reconstruction) provides images with sub-mm spatial resolution and temporal resolution of less than 4 seconds (18). PR-hyperTRICKS enables the acquisition of high frequency data up to 2 minutes after peak arterial enhancement using radial non-Cartesian projections; this sequence provides twice the spatial resolution (19).

Techniques other than TRICKS have been proposed to improve the depiction of distal arteries. Multiphase 2D sequences do not allow reconstructions in different planes. Parallel imaging techniques, including GRAPPA developed by Siemens, have also been described (17, 20). Schmitt describes an imaging protocol starting with the acquisition of 5 phases of 20 seconds each over both legs using parallel imaging followed by reinjection and acquisition over the upper and middle stations (17). Results with parallel imaging are superior to results from standard MRA, especially at the subpopliteal segments (20). Intra-arterial MRA, proposed by Huegli in 2006, has a sensitivity of 91% with specificity of 71%. Similar to catheter angiography, this technique is invasive and requires dedicated equipment only available in a few centers (21). The type of contrast used and the injection protocol also play an important role to improve the depiction of distal arteries. Contrast agents with high relaxivity (GdBOPTA, MultiHance®), likely to produce improved intravascular enhancement due to slower interstitial migration, improve the specificity of MRA for evaluation of distal arteries with reduction of non-interpretable subpopliteal segments (22). Fast injections should be avoided since they cause a modulation of k-space filling with overall degradation of image quality. A rapid acceleration of the curve of contrast arrival causes artifacts of kinetic blurring and truncation, worsened by temporal interpolation. Carroll has demonstrated that these artifacts could be reduced with a slower injection without alteration in image contrast. A slow injection increases the duration of the bolus, lengthens the acquisition time for improved image resolution.
allows the acquisition of a larger number of arterial phases and reduces the concentration of contrast in the venous system. In addition, during a slow injection, the peak of recirculation occurs before the end of the initial bolus, which tends to improve signal quality (23).

Our study has some limitations. The patient population is very specific, introducing a selection bias. The imaging work-up of PAD is more frequently performed with CTA, more available than MRA, and usually adequate for the evaluation of proximal lesions of the aorta, iliac, femoral and popliteal arteries. MRA was typically performed for patients with advanced disease of the distal arteries (chronic ischemia, critical ischemia) and/or renal failure where the injection of iodinated contrast material was contraindicated. Our patient population was mainly composed of older individuals (mean age of 74 years) with multifocal disease involving lower leg arteries. The high rate of venous contamination is due to the large number of patients with chronic ischemia and trophic skin changes resulting in inflammatory changes leading to early venous drainage. The inclusion of a few patients with claudication presenting few or no distal lesion probably had no impact on our results, with normal arteries being better assessed but with no significant difference between standard and TRICKS MRA. We have not compared results of MRA to results of catheter angiography, which remains the gold standard in France, because we consider that MRA has been shown to be equal if not superior to angiography in the evaluation of lower leg arteries (16). Additional limitations are present. The order of sequence acquisition was modified during the study. Initially, the 3 station MRA was acquired first. However, some patients had difficulty remaining still for the TRICKS sequence. As a result, we have modified the order of acquisition to begin with the TRICKS MRA. We have also changed the coil used for the lower legs by replacing the phased array torso coil by the dedicated vascular coil (HD lower leg array) with improved resolution and contrast. Volumetric evaluation of the best arterial phase was not always possible because all native images were not always stored. The reviewers were not independent and they were not blinded to patient names, which may have introduced a bias in spite of the time allowed between image review sessions. Image review was also not entirely standardized since each reviewer could reconstruct one phase or another. In conclusion, the multiphase TRICKS sequence appears to provide useful complementary information in the evaluation of the lower legs. It provides significant improvement in the evaluation of distal arteries with reduced venous contamination especially in patients with trophic skin changes and excellent interobserver agreement.

References

21. Huegli RW, Aschwanden M, Bongartz G et al. Intraarterial MR angiography and
