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SYNOPSIS: Magnetic resonance angiography of the calf and pedal arteries is challenging due to the issues of venous contamination and small vessel size. Therefore, contrast-enhanced MRA is typically supplemented with TOF imaging below the knee. In this study, we compared the conventional TOF sequence with 3D contrast-enhanced time-resolved MRA and 3D bolus chase MRA for calf and pedal imaging. Both 3D methods are superior to TOF imaging in the evaluation of arterial length and stenosis grade. Furthermore, the time-resolved technique adds important dynamic information about blood flow direction.

INTRODUCTION: Gadolinium-enhanced magnetic resonance angiography (MRA) has become an established alternative to digital subtraction angiography. With moving table technology, bolus chase methods allow acquisition of sequential multi-station three dimensional (3D) images from the abdomen to the feet in under 2 min [1]. Problems arise, however, in the distal station (below the knee) because of limitations in timing of the third acquisition. Time of flight imaging (TOF) is typically used as an alternative means of assessing the distal station, but at the expense of added study time [2]. An alternative approach is the use of time resolved contrast-enhanced (CE) MRA, which can provide information about distal arterial patency as well as dynamic information about blood flow. While this approach has been reported using 2D methods, we have applied a fast 3D MRA technique to obtain time-resolved (TR) MRA and compared this method with third station 3D bolus chase (BC) MRA and conventional TOF imaging.

METHODS: Twenty patients (10 M, 10 F, mean age 68 yrs, age range 36-88yrs) underwent MRI following an IRB-approved protocol at 1.5 T (Quantum, Siemens) using a peripheral phased array coil. 2D TOF images were obtained from the tibiotalar joint to the metatarsal heads (431/7/70°, voxel size 1.5 x 1.4 x 3.0mm) and through the calves, from the expected location of the trifurcation to the tibiotalar joint, (351/7/70°, voxel size 1.5 x 1.4 x 4.0mm) in an average acquisition time of 5 min without ECG-gating. 3D (TR) MRA was then performed through the same field of view using two oblique sagittal slabs (4.51/1.49/30°, interpolated slice thickness 2.5 mm, voxel size 1.8 x 1.8 x 2.5mm with centric reordering, acquisition time 8.4 sec). Following a 20 second scan delay, the TR sequence was repeated 10 times following injection of 10 ml of Gd-DTPA at 2 ml/sec. Subsequently, three-station moving table technology was utilized to perform routine 3D CE (BC) MRA of the extremities, with the third station positioned comparably to the other imaging techniques (4.3/1.46/30°, voxel size 1.5 x 1.2 x 1.3 mm). The BC imaging of the third station occurred on average 30 seconds after the initiation of imaging at the first station, the timing of which was determined based on a test bolus. For the BC protocol, 20 ml Gd-DTPA were injected at 2 ml/sec, followed by 10 ml at 1 ml/sec.

Two readers, blinded to patient identity, independently reviewed the TOF, TR, and BC sequences in a randomized order, and differences were resolved by consensus. MIPs as well as the source data were available for evaluation. Any factors which hindered interpretation were documented. The visualized lengths of the anterior tibial, peroneal, and posterior tibial arteries to the level of the talar dome were scored as follows: 1, >50% of the expected length of a normal artery; 2, <50% of the expected length; and 3, total occlusion. Any stenoses were scored as follows: 1, <50% and 2, >50%. In cases of multiple stenoses, the most severe site was recorded.

Results: Factors inhibiting diagnosis included in-plane saturation in the TOF sequences (n=12 patients), off axis resolution for the TR sequences (n=4 patients), and venous contamination (n=8 patients) for the BC sequences. A total of 229 segments were visualized in this study and were scored in terms of stenosis grade. All 229 were seen on the TR sequences, 223 were visualized via BC imaging, and 218 were demonstrated on the TOF sequences. Of note, 2 segments (in 2 patients) were seen exclusively on the TR sequences. A total of 120 segments (the calf arteries) were scored in terms of length visualized.

As demonstrated in Figure 1, there was no significant difference in the visualization of the calf arterial lengths among the three techniques. However, for stenosis grading, the BC method was superior to the others (BC vs. TOF, p=0.0001; BC vs. TR, p=0.032). When the pedal arteries were analyzed separately in terms of stenosis, both 3D methods were superior to the TOF technique (TR vs. TOF, p=0.004; BC vs. TOF, p=0.0023). Furthermore, the TR sequences had the added benefit of demonstrating retrograde flow in 7 segments (3 patients).

DISCUSSION: Recent advances in MR technology, including the use of peripheral phased-array coils and moving table technologies, provide alternative approaches to the evaluation of distal station (calf and pedal) arteries that may prove more time efficient and informative than routine time-of-flight imaging. For the calf and pedal arteries, both 3D time-resolved and bolus chase methods are superior to non-ECG gated TOF imaging, with time-resolved MRA providing valuable complimentary assessment of potential retrograde filling.

REFERENCES:


Figure 1. Agreement with Reference Assessment

<table>
<thead>
<tr>
<th></th>
<th>TOF</th>
<th>TR</th>
<th>BC</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>95/120 (79%)</td>
<td>102/120 (85%)</td>
<td>105/120 (88%)</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Stenosis</td>
<td>169/218 (78%)</td>
<td>192/229 (84%)</td>
<td>202/223 (91%)</td>
<td>&lt;0.05 *</td>
</tr>
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BC was significantly better than TOF and TR.

Figure 2. A MIP of the TOF sequence (a) fails to show the pedal arteries to the extent that the TR (b) and BC (c) images do. There is also in-plane saturation of the proximal right anterior tibial artery on the TOF MIP. Note the higher resolution of the 3D (BC) MIP.