Comparison of Magnetic Resonance Angiography (MRA) and Duplex Ultrasound Arterial Mapping (DUAM) Prior to Infrainguinal Arterial Reconstruction


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Objective: the purpose of this study is to compare Magnetic Resonance Angiography (MRA) to Duplex Ultrasound Arterial Mapping (DUAM) and intraoperative findings to determine the clinical accuracy of MRA for planning lower extremity revascularization procedures.

Methods: forty-two patients who underwent lower extremity revascularization procedures had both MRA and DUAM evaluations. These data were analyzed retrospectively and two distinct endpoints were considered. First, we compared the MRA and DUAM findings for aorto-iliac, femoral-popliteal and infra-popliteal segments to intraoperative findings and evaluated the degree to which they agreed. Second, if there was a disagreement between imaging modalities, it was established whether a change in operative procedure would have resulted.

Results: MRA and DUAM findings agreed in 26 of 31 cases (83%) of aorto-iliac segments, in 25 of 31 cases (81%) of femoral-popliteal segments, and in 16 of 21 cases (76%) of infra-popliteal segments. In total, DUAM agreed with intraoperative findings in 98% of cases while MRA agreed in 82% (p < 0.001). Disagreement between intraoperative findings and DUAM lead to an alternate surgical procedure in only one case (2%) while disagreement with MRA lead to a different procedure in 38% of cases (p < 0.001).

Conclusions: these data show that MRA is not yet adequate to replace conventional angiography and is less accurate than DUAM. Further improvements are necessary before MRA can be used as the sole modality for formulation of a pre-operative plan for lower extremity revascularization.

Key Words: Duplex ultrasound; MRA; Lower extremity; Arterial imaging.

Introduction

While contrast arteriography (CA) has been considered the gold standard for the visualization of arterial anatomy and identification of arterial lesions, it has been associated with significant local and systemic complications including hematoma, anaphylaxis, arterial injury and renal failure.1-5 This has served as an impetus for the search for less invasive imaging techniques that offer comparable accuracy and precision for vascular imaging. Utilizing recent advancements in Magnetic Resonance Angiography (MRA) techniques, it may be possible to obtain images of the lower extremity arteries that are of comparable quality to CA with fewer complications. Based on these data, some authors even suggest that MRA may supplant CA as the gold standard for lower extremity vascular imaging.6-8 In addition, the development and application of high-resolution duplex ultrasonography offers an alternative method to noninvasively image the arterial tree. Previous studies have demonstrated that Duplex Ultrasound Arterial Mapping (DUAM) may be an acceptable substitute for evaluating lower extremity arterial disease for infrainguinal arterial reconstruction and, in fact, provides information not available from other modalities.9-11

The question remains, however, whether any imaging modality can be as effective as CA in the planning of lower extremity revascularization procedures. Previous studies have attempted to compare MRA or DUAM to CA but have not compared all three techniques for the entire lower extremity. In addition, little mention was made of actual intraoperative findings or of clinical relevance of errors made by imaging modalities. The purpose of this study is to compare MRA to DUAM and intraoperative findings (intraoperative angiogram, graft...
pressure measurements and intraoperative examination of the target vessels) to determine the clinical, rather than relative, accuracy of MRA and DUAM for planning lower extremity revascularization procedures. This is a report of our experience with 42 patients who underwent DUAM and MRA evaluations and the clinically significant differences that result from the use of DUAM and MRA as the sole preoperative imaging modality.

Methods

From January 1999 to February 2001, 42 patients who underwent lower extremity revascularization procedures had both MRA and DUAM evaluations (Tables 1 and 2). The lower extremity was divided into the aorto-iliac segment (comprising the aorta, common iliac artery, and the external iliac artery), the femoral-popliteal segment (comprising the common femoral artery, superficial femoral artery and the popliteal artery above and below the knee), and infra-popliteal segment (comprising the anterior and posterior tibial arteries, peroneal artery, and the dorsalis pedis artery). All patients were included who had both MRA and DUAM evaluations that included the area of stenosis as well as the segment containing the vessels used for bypass. First, we compared the MRA and DUAM findings for each segment to intraoperative findings. Intraoperative findings were defined as exploration of the vessels, intraoperative angiogram and graft pressure measurements. For various reasons, many patients did not undergo a complete MRA or DUAM examination. Because of this, one criterion for inclusion in the study was that the partial examination must have included the segment containing the stenosis as well as the vessels to be used for bypass. Second, when DUAM and MRA disagreed, a single surgeon determined whether or not that disagreement would have altered the surgeon’s choice of procedure had either been used as the sole preoperative imaging modality. In all cases, the patient had a revascularization procedure, CA or both and the anatomy and pathology were documented. These cases were not consecutive as there was a large percentage of patients who could not undergo MRA examination.

Study design and bias

While this is a retrospective study, this fact eliminated any selection bias since the only criteria for enrollment in the study were having adequate MRA, DUAM and intraoperative evaluations as described above. The use of a single surgeon to evaluate the clinical endpoint of choice of surgical procedure eliminated inter-observer bias. Further, the use of this clinical endpoint reflects our belief that clinical usefulness of the imaging modality is more important than correlation between the various imaging modalities.

Duplex ultrasound arterial mapping

Ultrasound examinations were performed using an ATL HDI 3000 or 5000 duplex color scanner and employed several scan-heads including linear 7–4 MHz, linear 10–5 MHz, linear 12–5 MHz, curvilinear 2–5 MHz, and phased array 3–2 MHz. Arteries were scanned in cross sectional and longitudinal views to visualize both the wall and lumen of the vessel. High quality B-mode and color-flow images of the plaque and residual lumen as well as Doppler velocity spectra were obtained and used to determine the degree of stenosis and to draw a schematic map of the arteries of the lower-extremity.

To grade the lesions, a peak systolic velocity ratio (PSV) greater than two was used to distinguish hemodynamically significant lesions (>50%) from lesions which were not hemodynamically significant. A PSV ratio greater than three corresponded to >70% stenosis. Long arterial narrowing in arteries with diffuse disease was also observed. Aorto-iliac disease was evaluated by direct observation of the vessel and

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Table 1. Patient population.

<table>
<thead>
<tr>
<th>Indication for revascularization</th>
<th>Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claudication</td>
<td>16 (38)</td>
</tr>
<tr>
<td>Rest Pain</td>
<td>9 (21)</td>
</tr>
<tr>
<td>Ischemic ulcers</td>
<td>10 (24)</td>
</tr>
<tr>
<td>Gangrene</td>
<td>7 (17)</td>
</tr>
<tr>
<td>Risk Factors</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>21 (50)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>30 (71)</td>
</tr>
<tr>
<td>Smoking</td>
<td>18 (43)</td>
</tr>
<tr>
<td>Renal insufficiency*</td>
<td>9 (21)</td>
</tr>
<tr>
<td>ESRF12</td>
<td>10 (24)</td>
</tr>
<tr>
<td>Age range</td>
<td>39–88</td>
</tr>
<tr>
<td>Average age</td>
<td>76</td>
</tr>
<tr>
<td>Male</td>
<td>29 (69)</td>
</tr>
</tbody>
</table>

*Creatinine level > 1.5 mg/dL.12

Table 2. Revascularization procedure.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass to popliteal artery</td>
<td>17 (41)</td>
</tr>
<tr>
<td>Bypass to infra-popliteal vessel</td>
<td>19 (45)</td>
</tr>
<tr>
<td>Angioplasty alone</td>
<td>5 (12)</td>
</tr>
<tr>
<td>Angiogram alone</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Bypass plus angioplasty</td>
<td>9 (22)</td>
</tr>
</tbody>
</table>
spectral analysis of the common femoral artery with acceleration time of >140 ms considered abnormal. Previous patent and occluded bypass grafts were also imaged and reported.

Ultrasound examination for mapping began with the aorta and iliac arteries and proceeded down the leg to the popliteal artery. The popliteal artery was scanned from both the medial and posterior approach. The more distal arteries, including the tibio-peroneal trunk, peroneal and anterior tibial arteries were then scanned with the patient in the lateral decubitus position. Finally, the patient was returned to the supine position for the study of the posterior tibial, dorsalis pedis, common plantar and iliac arteries and the aorta. Many patients underwent this complete protocol which averaged 45 min in duration. Some patients underwent a partial evaluation, but to be considered complete the area of stenosis and the segment containing vessels used for anastomosis must have been imaged. Incomplete or inadequate examinations were not included in the study.

Magnetic resonance arteriography

MRA was performed using a 1.5 Tesla whole-body scanner (Siemens Medical Systems, Iselin, NJ, U.S.A.). For all patients involved in the study, lower extremity MRA images were obtained using the standard protocol in place at our institution at the time our data were collected. Parameters for the study were a repetition time of 40 ms and an echo time of 1.6 ms. T1 weighted three-dimensional gadolinium enhanced imaging of the aorto-iliac system to the level of the knees was performed in a body array coil with a flip angle of 70°. Prior to the scan, 40 cc of gadolinium contrast material was infused at a rate of 2 cc/s using a power injector. Below the knees, two-dimensional EKG triggered time of flight MRA was performed using a combination of the phased array coil and the head coil with a flip angle of 30°. Images below the knee were not gadolinium enhanced. Maximum intensity projections and source images were used in the interpretation of the study.

All patients included in the study had an MRA examination. Twenty patients had a complete MRA exam of the entire lower extremity. For various reasons, including patient intolerance of the exam, patient’s symptoms, location of the pathology and scheduling difficulties, 22 patients had only partial MRA examinations. As this was a retrospective study, a quantification of these reasons was not possible. As stated above, one of the inclusion criterion for the study was that the patient have had an MRA examination of the segment containing the stenosis as well as the vessels to be used for bypass. Of those patient’s undergoing a partial MRA examination, the aorto-iliac segment was evaluated in 31 patients, the femoral-popliteal segment was evaluated in 31 patients and the infra-popliteal segment was evaluated in 21 patients. Again, as this was a retrospective study, data regarding the time required to complete a full or partial MRA examination is not available. MRA results were interpreted by radiologists with extensive experience with MR and who were not aware of the results of other lower extremity imaging modalities.

Intraoperative findings

Lower-extremity arteries were evaluated via intraoperative examination of the reported lesion. As previously mentioned, this term comprised exploration of the vessels, intraoperative angiogram and graft pressure measurements. In six cases, CA was performed without further intraoperative confirmation. In total, 35 (83%) patients underwent CA examination. The remaining seven (17%) patients were satisfactorily examined utilizing visualization of the vessels and pressure measurements. No patient was evaluated using visualization of the vessels alone. Upon completion of the bypass procedure, completion arteriography of the run-off vessels was also performed. Pressure measurements were obtained and a systolic pressure gradient >20 mmHg between the distal anastomosis and radial artery warranted on-table angiography, repair of the inflow lesions and assessment of the conduit.

Pre-operative plan

Actual operative procedures were based on both DUAM and CA. Although the surgeon was not blinded for this study, it was our belief that the accuracy of MRA was unproven for use as a sole pre-operative imaging modality. Additionally, a single surgeon determined whether the same pre-operative plan would have been chosen using MRA and DUAM. This eliminated inter-observer bias since the surgeon applied the same criteria to each in determining his choice of procedure.

Retrospective analysis of planned procedure

In analyzing the data, two distinct endpoints were considered. The official reports and images generated...
by DUAM and MRA were analyzed. Reported lesions were classified as mild-moderate (<70%) or severe-occluded (70–100%) for each imaging modality. Following the procedure, the DUAM and MRA findings were compared with the intraoperative findings and the accuracy of each imaging modality was assessed.

In addition, the actual revascularization strategy undergone by the patient was analyzed with respect to DUAM and MRA findings separately to determine the clinical relevance of any differences in the findings. Since DUAM had been used in the pre-operative planning of the procedures, it was determined whether DUAM had been accurate in the pre-operative assessment of the patient and whether the procedure dictated by DUAM had been carried out. Further, it was determined whether the same procedure would have been undertaken had MRA been used instead of DUAM or if the MRA findings would have dictated a different procedure. In cases where DUAM was shown to have been incorrect or use of MRA would have resulted in a different procedure, the nature of the error made by the imaging modality was determined.

**Statistics**

Data were compared using chi-square test and student, t-test (Winks 4.21, Texasoft TX and Instat, Graphpad; CA). Kappa statistics were performed using Stat view (SAS Cary NC). Significance was set at $p < 0.05$ for all comparisons.

**Results**

MRA and DUAM findings agreed in 26 of 31 cases (83%) in which the aorto-iliac segment was imaged, in 25 of 31 cases (81%) in which the femoral-popliteal segment was imaged, and in 16 of 21 cases (76%) in which the infra-popliteal segment was imaged.

**Comparison of modalities for the aorto-iliac segment**

For the aorto-iliac segment, DUAM agreed with intraoperative findings in 31 of 31 cases ($\kappa = 1.0$) while MRA agreed in 25 of 31 cases ($\kappa = 0.834$). This was a significant difference ($p = 0.01$). In all six cases of disagreement, a different operative procedure would have been undertaken had MRA been the sole pre-operative study (6 of 31 cases, 19%).

**Classification of MRA errors**

For our purposes, errors were defined rather liberally as misinterpretations drastic enough to cause a change in the procedure had the imaging modality been used as the sole pre-operative study. Errors made by MRA can be divided into three categories: overestimation of the lesion, underestimation of the lesion, and inaccurate localization of the lesion.

MRA overestimated the severity of the lesion in three cases (4% of all cases) accounting for 20% of the total cases in which MRA findings were erroneous. In overestimating the lesion, MRA findings erroneously suggested that the revascularization
procedure actually performed was not possible. MRA underestimated the severity of the lesion in ten cases (12% of all cases) accounting for 67% of the total cases in which MRA findings were erroneous. MRA labeled two anterior tibial arteries as diminutive when in fact they were of normal size (1.5 and 1.3 mm) but had extremely low blood flow rates (5 and 6 cm/s). Ultrasound identified this low flow state as distinct from stenosis, and the vessels were used for distal anastomosis. An angiogram would have been added if MRA were relied upon as the sole imaging modality. Use of pre-operative MRA containing underestimation errors results in the planning of inappropriate procedures to diseased and inadequate vessels. MRA had difficulty with localization of lesions in two cases (2% of all cases) accounting for 13% of the total cases in which MRA findings were erroneous. The ability to accurately localize an area of stenosis is of the utmost importance in planning an efficient and successful revascularization procedure.

Ultrasound misinterpreted only two lesions, both in the distal circulation. In one case, DUAM read a posterior tibial artery as open with extremely low flow when in fact the vessel was severely stenotic. In this case, however, no alternatives were available and the posterior tibial artery was used for anastomosis despite the lesion. In the second case, DUAM identified a calcified peroneal artery as mildly diseased when it was actually severely stenotic.

**Discussion**

**Considerations regarding the use of MRA**

MRA has several advantages including a low rate of medical complications and the ability to construct three-dimensional as well as axial images, but can be problematic. A disturbingly large proportion of patients were unable to undergo MRA examination. Many patients cannot tolerate the exam either because they are claustrophobic, are not able to lie supine for prolonged periods, or are not able to hold their breath during portions of the exam. In addition, it is well known that special considerations must be made for the use of external assist devices that containing metal. Certain tattoos have also been reported to cause burns due to metal compounds in the ink used. At our institution, MRA exams were scheduled several days after the initial request. More importantly, the exam may require as long as one hour to perform. This makes the exam less tolerable for patients and, for less stable patients or patients with acute limb-threatening ischemia this precludes the use of MRA altogether.

Several authors have studied the use of MRA for evaluation of lower extremity arterial disease from diverse perspectives and have come to equally diverse conclusions. One author concluded that there is great potential for use of MRA in the primary diagnosis of peripheral arterial occlusive disease. Another author determined that neither ultrasound nor MRA was sufficient to replace conventional angiography for the evaluation of aorto-iliac arterial disease. According to a third study, MRA was sensitive enough to detect many arterial lesions in the lower extremity but the specificity was extremely poor. In this study it was found that MRA could not be considered a reliable substitute for conventional angiography. The enormous disparity in results from these various studies, as well as our own experience, leads us to believe that claims about the use of MRA as a sole pre operative imaging modality are premature. Studies by authors who argue that MRA may be used in lieu of other imaging modalities still required that MRA be used only in centers where the technique had been validated against the gold standard of CA.

An often overlooked fact is that despite the incredible three-dimensional images rendered, MRA only studies the lumen of the vessel and not the vessel itself. Unlike DUAM, which retains the ability to image arterial anatomy directly, MRA infers the state of the vessel from the flow of blood within it. This is sufficient for focal stenoses that dramatically decreases the lumen size over a relatively small portion of the vessel, however because of this inability to image the vessel wall, more diffuse vascular abnormalities such as long lesions or diffuse wall thickening may be missed. Due in part to this deficiency, we found that MRA both overestimated and underestimated lesions meaning that MRA lacks both sensitivity and specificity for arterial lesions.

One prolific and respected author compared MRA to CA and found MRA to be superior in an initial study and claims that MRA may replace CA in many patients. In a more recent study, he addresses the question of pre-operative planning with non-invasive imaging modalities but, unfortunately, does not include an evaluation of DUAM. The basis for many of these claims is a study of 51 patients with peripheral vascular disease who underwent both MRA and CA examinations. It is argued that MRA never overestimated the severity of a lesion or reported the presence of a lesion when one did not exist. In fact, in the 48% of cases in which there was a disagreement between MRA and CA, all disagreement involved the discovery of more patent distal
vessels using MRA than using CA. The study author suggests that this indicates the superior sensitivity of MRA to detect patent vessels. Yet, other studies have not demonstrated the ability of MRA to reveal “angiographically occult” vessels to such a degree.7,21 One study from Germany did demonstrate somewhat similar findings.22 Unfortunately, it included only the vessels of the distal calf and foot. The study was further limited by the fact that imaging modalities were compared in only 24 patients without consistent independent verification of the results. One meta-analysis from the Netherlands compiled 34 articles written over the past 15 years and found that MRA was highly accurate for the detection of stenosis >50%.23 The authors go on to state that studies have repeatedly found that MRA can detect infrapopliteal vessels not visible on CA. They cite four papers in defense of this assertion all of which were published by Carpenter and his group. While we recognize the significance of these findings, we were interested in determining how effectively MRA could differentiate between lesions that were greater than and less than 70% stenotic as we feel this is more clinically relevant.

A study by Cambria et al. found MRA to be extremely sensitive to arterial lesions.24 In this series, MRA never underestimated lesions relative to CA. In fact, MRA actually identified more stenoses than did CA overestimating arterial disease relative to CA findings in 3% of cases. While this finding is not significant on its own, it is exactly the opposite of the results reported in Carpenter’s study.20 At the risk of overanalyzing this difference, this seems to indicate that MRA results depend on who is reading them and that a bias for overestimating or underestimating lesions or variations in angiographic technique may exist at different institutions. In subsequent investigations, this author claims that MRA may replace CA in patients who are at increased risk for CA evaluation or when additional findings indicate that a straightforward aorto-femoral or femoral-popliteal reconstruction is likely.7 This was a multi-center trial and the findings are far less absolute than those of previous studies. Here the author recognizes technical constraints on the use of MRA and the existence of a learning curve with regard its use. Most important, however, is that preoperative treatment plans devised using CA and MRA separately agreed in only 85% of cases. We feel that an error rate of 15% is unacceptable in the clinical practice of planning revascularization procedures.

Another meta-analysis purported to compare the accuracy of DUAM and MRA.25 These authors compiled many studies for each imaging exam, but include no studies that compare both modalities in the same paper. Their results are compelling and the study is well designed, however they conclude that ideally MRA and DUAM should be compared in the same patients which is what we have endeavored to do here.

Our own experience with MRA revealed an 82% agreement with intraoperative findings. By way of contrast, in our study DUAM was found to agree in 98% of cases. It appears that this MRA technology lacks the specificity to accurately distinguish between true stenoses and the other confounding conditions described above. Admittedly, at the time our data were being collected, Time-of-Flight MRA was being used for vessels below the knees. This had been the standard protocol and until recently was the protocol being used at our institution. Since it is extremely expensive to update MRA equipment with every new advance in technology, we feel that it is very likely that many institutions are continuing to utilize TOF-MRA. New techniques making use of gadolinium contrast “bolus chasing” and step-tables may have an effect on the accuracy of MRA. Interestingly, however, TOF-MRA is often thought to overestimate the severity of lesions. In our series, there was only one case that involved the overestimation of a lesion by MRA in the infra-popliteal segment imaged by TOF-MRA while two cases of overestimation occurred in the aorto-iliac segment for which gadolinium enhancement was utilized. Three of the four errors made by TOF-MRA in the infra-popliteal segment were actually underestimation errors. Therefore, despite the use of TOF-MRA in this study, we feel that the results continue to be of interest.

Considerations regarding the use of ultrasound

We have reported our success with DUAM in previously published papers.9,26 We do, of course, recognize that DUAM is an operator dependent imaging modality and that our technicians are extremely skilled and are well versed in vascular anatomy and the relevant surgical procedures with experience in over 500 DUAM exams.

Our experience has shown that DUAM is excellent at revealing vessels that are stenotic but not occluded. This is in part because unlike MRA, the results of DUAM are enhanced but not dependent upon blood flow through the vessel as DUAM has the advantage of being able to directly visualize the vascular anatomy. Furthermore, visualization of the blood flow and use of duplex allows turbulent and decreased rate of flow to be easily identified. DUAM can be used to assess the degree of calcification of the vessel wall and aid in the identification of the most appropriate site
for anastomosis. Finally, the DUAM technician can adjust the study in real-time to better visualize the vessel. This, of course, requires adequate training and experience and is a frequent criticism about ultrasound techniques. It should be reiterated here, however, that MRA also requires extensive experience, skilled technicians and radiologists who are knowledgeable with regard to vascular anatomy and the relevant surgical procedures.

Future investigations

The need for further studies comparing DUAM, MRA and CA is clear. Our experience here is limited by the fact that not every patient had a study of the entire lower extremity. Furthermore, our study is retrospective representing our initial experience with a limited number of patients. There is information relevant to the use of MRA that we were unable to obtain. It would be interesting to determine how many of these patients who were unable to undergo an MRA examination could not tolerate the exam compared to the number who had actual contraindications to MRA use. Additionally, such problems as cost and availability and scheduling of the MRA exam are extremely important factors if MRA use is to be expanded.

The results of this study are consistent with our previous experience with DUAM. With DUAM, the pre-operative findings coincide very closely with the intraoperative findings and result in an accurate and effective pre-operative plan. With MRA, however, the pre-operative findings were inaccurate in as many as 18% of cases and each would have required some change in the planned procedure. These data show that MRA is not yet adequate to replace conventional angiography and is less accurate that DUAM for imaging lower extremity arterial anatomy and pathology. We are not arguing that MRA is not suited for this application. On the contrary, we have attempted to identify problem areas so that techniques can be modified and the accuracy of the modality improved.

We do maintain, however, that further improvements in both technology and technique are necessary before MRA can be used as the sole modality for formulation of a pre-operative plan for lower extremity revascularization.

References


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