Virtual Digital Subtraction Magnetic Resonance Angiography and Flow Evaluation in a Chronic Aortic Dissection using a Cine Fast Interrupted Steady-state Technique in Combination with Arterial Spin Labeling (cFASL)

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Introduction

Aortic dissection is the most common acute aortic syndrome and is associated with high morbidity and mortality [1, 2]. A tear in the intimal layer of the wall of the aorta allows blood to extend in between the layers of the wall of the aorta creating a false lumen [3]. Patients typically present with severe, tearing inter-scapular pain. Over time, the pain extends inferiorly along the course of the dissection flap as it enlarges. Emergent diagnosis is usually made on cross-sectional imaging, most commonly CT angiography (CTA) or echocardiography. Follow up imaging can be performed with CTA or with MR angiography (MRA), with the latter often considered in order to reduce lifetime radiation exposure. Both modalities are most commonly performed after administration of intravenous contrast.

1 A Chronic Stanford type B aortic dissection.

1A A 3D reconstruction of the initial contrast enhanced CT angiogram that was performed in the emergency room. The dissection flap (arrow) is identified extending from the distal arch into the right common iliac artery.

1B Coronal oblique non-contrast TrueFISP single image from cine series demonstrates the dissection flap in the abdominal aorta with two lumens visible.

1C From left to right, top then bottom row, selected sequential images from the oblique coronal cFASL dynamic sequence demonstrating differential flow in the true (arrow) and false (arrowhead) lumens. Three 9 mm slices were acquired in the coronal oblique plane and combined to produce this sequence.
Fast Interrupted Steady-State (FISS) is a prototype radial bSSFP pulse sequence where the steady state is periodically interrupted resulting in images with excellent suppression of background fat signal as well as unwanted flow and off resonance artifacts [4]. Arterial spin labeling (ASL) is a non-invasive MR imaging technique employed to evaluate blood flow or tissue perfusion. A selective radiofrequency (RF) pulse is used to tag the arterial blood [9]. It is then possible to visualize the labeled blood as it travels downstream within the artery by subtracting the labeled image with a separately acquired unlabeled one. Cine FISS ASL (cFASL), a new technique that combines a cine FISS acquisition with ASL, has been shown to provide a high temporal resolution, visually appealing depiction of blood flow patterns and quantification of peak velocity within the aorta and its branches in healthy volunteers [5]. Here, we illustrate the application of cFASL in the evaluation of differential flow within the true and false lumens of a chronic aortic dissection.

Patient history
A 46-year-old male with a 15 year history of type 2 diabetes mellitus and spinal surgery 8 years previously for spinal tuberculosis (Potts Disease) presented for follow up of an aortic dissection. He had presented to the emergency department one year prior with severe atraumatic pain between his shoulder blades radiating to the upper abdomen after getting out of bed. Upon presentation, he was noted to be hypertensive with symmetric blood pressure in the upper limbs. He was diagnosed with a Stanford type B aortic dissection on CT angiography. The dissection flap extended from just beyond the origin of the left subclavian artery in the distal arch, through the descending thoracic and abdominal aorta and right common iliac artery, terminating in the right external iliac artery. The celiac axis, superior mesenteric artery, inferior mesenteric artery, and left renal artery arose from the true lumen while the right renal artery arose from the false lumen. He was medically managed with strict blood pressure control and discharged from the hospital two weeks later. Due to his young age and the need for ongoing surveillance of the dissection, follow up was performed with non-contrast MRA of the chest, abdomen and pelvis to minimize ionizing radiation exposure.

In addition to the standard MRA imaging protocol, we used the cFASL non-contrast dynamic MRA technique to evaluate flow patterns, including differential flow in the true and false lumens of the aortic dissection and origins of the major branches of the abdominal aorta.

Methods
MR Imaging
With informed consent and institutional review board approval, imaging was performed on a 1.5T MR system (MAGNETOM Avanto Dot, Siemens Healthcare, Erlangen, Germany) with a standard phased array body coil. No intravenous contrast was administered. Standard localizer scans were obtained, followed by breath-hold, non-enhanced, ECG-gated quiescent inflow slice-selective (QISS) MRA of the abdominal aorta [6].
cFASL was performed in the region of the abdominal aorta in coronal oblique and axial oblique planes. Three 9 mm slices were obtained for the coronal oblique sequence and a single 6 mm axial slice was obtained for the axial sequence. Sagittal oblique cFASL was performed in the region of the right iliac arteries using a single 27 mm slice. Spin labeling was performed by applying a 25 mm thick adiabatic inversion radiofrequency pulse to inflowing arterial blood. Background suppression was achieved by complex subtraction of the labeled and unlabeled cine images, acquired on alternate RR intervals. Imaging parameters included TE ≈ 1.5 ms, TR ≈ 18 ms, FOV 240 × 240 or 300 × 300. A comparison coronal oblique cine bSSFP series was also obtained at the same level.

**Imaging findings**

Cine bSSFP imaging demonstrated the known dissection flap delineating the true and false lumen in the abdominal aorta (Figure 1). Coronal oblique cFASL non-contrast MRA provided a visually appealing, dynamic visualization of differential flows within the true and false lumens (Figure 1). Axial oblique cFASL at the level of the renal arteries demonstrated delayed progression of the tagged arterial blood through the right renal artery (which arose from the false lumen) indicating slow flow, compared to normal brisk progression of the labeled blood through the left renal artery (which arose from the true lumen) (Figure 2). Coronal cFASL at the level of the iliac arteries again provided dynamic visualization of differential flow within the true and false lumens of the dissection (Figure 3). Scan time for each slice of the cFASL sequence was approximately 60–70 s.

**Discussion**

This case demonstrates the capability of cFASL to depict dynamic flow patterns in an aortic dissection without the need for contrast agent.

The Stanford classification is used to differentiate aortic dissection cases between those who require urgent surgical repair versus medical management [7]. Type A dissections, which affect the ascending aorta and aortic arch, are managed surgically due to the high risk of life-threatening complications including coronary artery occlusion, aortic valve disruption and cardiac tamponade. Type B dissections, on the other hand, originate beyond the origin of the great vessels of the aortic arch. Initial management of type B dissections usually includes strict blood pressure control to prevent propagation of the dissection flap and monitoring for complications including renal and liver dysfunction, bowel and extremity ischemia due to occlusion of branches of the abdominal aorta and iliac arteries. If such management is successful, patients
will often have no surgical repair of the dissection in the acute phase. They will require periodic follow up with cross-sectional imaging to evaluate for propagation of the dissection flap or other complications including refractory pain, hypoperfusion, aneurysm and rupture [8]. Both CTA and MRA are most commonly performed after administration of intravenous contrast and typically provide static images of the extent of the dissection. Occasionally, it can be difficult to accurately discern the true and false lumens and the position of the aortic branch origins on static images alone. While 2D cine phase contrast MRI allows the measurement of through-plane blood flow, this is typically restricted to a few locations and is less useful for evaluation of in-plane flow over extended lengths of the vessels. Alternatively, 4D flow imaging permits evaluation of flow in multiple directions, but is time-consuming both to acquire and to process.

The cine FISS imaging technique has several advantages over cine bSSFP, namely homogeneous fat suppression and a reduction of artifacts caused by off-resonance effects and through plane flow [5]. Compared to bSSFP imaging cine FISS imaging provides similar signal for on-resonant spins while suppressing off-resonant spins more effectively. ASL has been extensively employed in the evaluation of cerebral blood flow across a wide spectrum of disease pathologies including dementia, brain tumors, and seizure disorders [10]. When ASL is combined with cine FISS (cFASL), it produces visually-appealing images of dynamic flow patterns over extensive lengths of the aorta [5]. Moreover, the use of image subtraction means that cFASL is largely insensitive to partial volume averaging.

In this case study, it was possible to evaluate differential flow within the true and false lumens of the aortic dissection and to identify the origins of the right and left renal arteries from the false and true lumens respectively. Previously, it was only possible to produce this type of dynamic imaging with invasive fluoroscopic angiography or, with a lower temporal resolution, with time resolved, contrast-enhanced MRA. However, cFASL can produce these dynamic, high temporal resolution images without ionizing radiation or need for administration of intravenous contrast.

The acquisition time for cFASL in this case was about 1 minute per slice, but can be as short as a single breath-hold. Due to substantial insensitivity to partial volume artifact, thicker slices, up to 30 mm, can be used as needed.

Due to the very high temporal resolution of 20 ms it is possible to measure peak flow velocity by calculating the maximal distance travelled by the arterial spins from one frame to another. Peak velocity calculations work well in normal vessels, but less so in vessels with significant stenosis or swirling flow due to the quick dispersion of the ASL bolus, as seen in the false lumen in this case.

A limitation of cFASL is the need for ECG gating which increases patient preparation time. The technique is also prone to off-resonance artifacts from nearby metal hardware.

Conclusion

This clinical case suggests that dynamic non-contrast imaging using cFASL may have a useful role in the evaluation of vascular pathology involving the aorta and its branches. Further studies will be required to investigate this.

References