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Feasibility of Image Fusion for Concurrent Magnetic Resonance Evaluation of Vessel Lumen and Vascular Calcifications in Peripheral Arterial Disease

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Abstract

With MR angiography (MRA) of peripheral arterial disease, calcifications are unapparent so a separate calcification-sensitive pulse sequence (proton density-weighted, in-phase three-dimensional stack-of-stars (PDIP-SOS)) is needed for complete assessment. We hypothesized that, despite being acquired separately, MRA and PDIP-SOS images could be co-registered and fused without loss of significant diagnostic information. In a prospective study of 15 patients, MR image fusion enabled the simultaneous display of vessel lumen and vascular calcifications similarly to CT angiography.

Introduction

Both CT angiography (CTA) and magnetic resonance angiography (MRA) are useful for the diagnostic evaluation of peripheral arterial disease (PAD) [1,2]. CT angiography is widely used to evaluate for stenosis and vascular calcifications. Alternatively, contrast-enhanced MRA can evaluate for luminal stenosis with the advantage of not exposing the patient to ionizing radiation or iodinated contrast agents. Nonenhanced MRA techniques are especially helpful for PAD patients with poor kidney function in whom gadolinium-based contrast agents are relatively contraindicated [3,4].

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CT angiography is an excellent technique for displaying both the vessel lumen and vascular calcifications, which are readily identified based on high density (as expressed in Hounsfield units). Accurate identification of vessel wall calcifications is important for several reasons. For instance, dense calcifications are generally avoided in selecting an access site for a percutaneous revascularization procedure. Aorto-iliac calcifications lower the success rate for percutaneous endovascular aneurysm repair [5]. The presence of vascular calcifications has adverse prognostic implications with regard to the risk of cardiovascular events and amputation in patients with PAD [6,7].

While CTA is advantageous in being sensitive to vascular calcifications, blooming artifacts from calcifications can worsen the apparent severity of a stenotic lesion. These artifacts can be especially problematic in small-vessel disease in diabetic patients [8]. While vascular calcifications are essentially unapparent with MRA and do not cause artifacts, the downside is that one can only use MRA to evaluate the vessel lumen and important diagnostic information about wall calcifications is unavailable. This limitation has been overcome using a proton density-weighted, in-phase three-dimensional stack-of-stars (PDIP-SOS) gradient echo sequence that accurately depicts wall calcifications in ilio-femoral vessels [9]. Unfortunately, separately-acquired images from MRA and PDIP-SOS MRI must then be viewed for complete assessment. This is relatively cumbersome and inefficient as compared to CTA, where both vessel lumen and calcifications can be simultaneously evaluated in a single set of projectional images. In order to overcome this limitation, we hypothesized that MRA and PDIP-SOS images could be spatially co-registered and then fused to concurrently display the vessel lumen and calcifications similarly to CTA, without the loss of significant diagnostic information. This hypothesis was tested in a prospective study of a small cohort of patients with PAD.

Materials and methods

This prospective study was approved by the Institutional Review Board of NorthShore University HealthSystem and informed consent was obtained. Fifteen patients (age range 52–84 years, 5 females) were consecutively recruited from those in whom CTA performed within the preceding six months demonstrated vascular calcifications in at least one ilio-femoral vessel segment. Patients were imaged using a 3.0 Tesla scanner (MAGNETOM Skyra Fit, Siemens Healthineers, Erlangen, Germany). Body and peripheral phased array coils were used for signal reception.

The imaging protocol consisted of a non-contrast quiescent-interval slice-selective (QISS) MRA pulse sequence to visualize the arterial lumen [10] followed by a PDIP-SOS pulse sequence. The PDIP-SOS sequence is designed to visualize vascular calcifications, which appear dark in contrast to the vessel wall, lumen, fat and muscle which show intermediate signal intensity. Imaging parameters are summarized in Table 1. The CTA studies were performed using a 64-slice scanner (SOMATOM Definition or SOMATOM FLASH, Siemens Healthineers, Forchheim, Germany) with standard clinical acquisition technique. Typical slice thickness was on the order of 0.6-mm to 1-mm and typical contrast dosage was 125 to 150 ml of Iohexol 350 (GE Healthcare Inc., Marlborough, MA). The viewing window for CTA images was selected to evaluate the vessel lumen and wall while minimizing

blooming artifact from dense vascular calcifications. Typical window width was between 4500–5000 with a window level of approximately 1900.

Image Fusion:

Image processing was performed at the level of the ilio-femoral junction. Semi-automated fusion of images from QISS and PDIP-SOS sequences was done using commercially available fusion software (Syngo, Siemens Healthineers, Forchheim, Germany). Bony landmarks (pubic symphysis, the greater and lesser trochanters of both femurs) that were readily identifiable in images from both sequences were selected to enable automated image registration, after which image fusion was done. Adequate superposition was verified by visually confirming the superposition of the landmark bony structures. A mixing ratio of 50% was applied so as to demonstrate imaging features from both QISS and PDIP-SOS in a balanced manner. The fused images were reconstructed in axial, coronal and sagittal planes for optimal analysis. A gray scale display was found to provide optimal contrast between the vascular lumen and the wall calcifications, with fused images showing the vascular wall calcifications as black and the flowing blood as white. We used a 16-bit gray scale display, with the contrast and window level settings set at 520 and 670 respectively for QISS, and 240 and 510 respectively for the PDIP-SOS images.

Image Analysis:

For qualitative image analysis, source images and multi-planar reformats for both CTA and fused MR were reviewed by a single observer with more than 4 years of experience in both imaging modalities. CTA images were taken as a reference and the fused MR images were analyzed for degree of confidence to detect the location, size and shape of calcifications at the ilio-femoral junction. Images were scored using a 5-point Likert scale as: 1- non-diagnostic, 2- poor, 3- fair, 4- good, 5-excellent, with each side being scored separately. Additionally, the vessel lumen at the ilio-femoral junction was evaluated for stenosis using a three-point scale: normal/mild (0–49%), moderate (50–74%) and severe stenosis (≥ 75%). Agreement of stenosis ratings between the CTA and fused MR images was assessed using Cohen's kappa (κ) analysis [11]. Kappa values for agreement were interpreted as follows: 0–0.20, none; 0.21–0.39, fair; 0.40–0.59, weak; 0.60–0.79, moderate; 0.80–0.90, strong; >0.90, almost perfect [12].

Results:

The semi-automated fusion of QISS MRA with PDIP-SOS required on the order of three to five minutes. Flowing arterial blood appeared bright and was highly conspicuous in QISS MRA images, but vascular calcifications showed poor contrast with background tissues which, like the calcifications, appeared dark. Vascular calcifications appeared dark and were highly conspicuous on PDIP-SOS images, but flowing blood within the arterial lumen showed intermediate signal intensity similar to background tissues. In distinction to source QISS and PDIP-SOS images, flowing arterial blood and vascular calcifications were both readily identified in fused images (Figures 1 and 2).

Of a total of 30 ilio-femoral vessel segments, 28 were available for analysis with two other segments excluded due to magnetic susceptibility artifacts related to hip prosthesis. Qualitatively, all fused MR images showed good-to-excellent confidence to detect vascular calcifications with a mean score of 4.0 (range 3–5). Regarding severity of stenosis, there was strong agreement between fused MR and CTA in evaluating for vessel stenosis (Table 2) with a $\kappa=0.80$ ($P<0.001$): 23 segments were classified as having mild stenosis by fused MRI while 21 segments were classified as mild by CTA; 3 segments were classified as having moderate stenosis by fused MRI while 5 were moderate by CTA; 2 segments were classified as having severe stenosis by both fused MRI and CTA.

Discussion:

It is helpful to have a roadmap of both the arterial lumen and vessel wall to plan vascular interventional procedures, e.g. to determine the presence of a vessel occlusion or dense vascular calcifications that might complicate percutaneous access or placement of an endovascular prosthesis. In this work, we demonstrated that fusing image data from nonenhanced QISS MRA and PDIP-SOS enabled simultaneous evaluation of the vessel lumen and calcifications, with strong correlation to CTA images.

The use of fused MR images can facilitate the planning process for percutaneous interventional procedures by providing a familiar, CTA-like display that simultaneously shows both the vessel lumen and wall calcifications. Another consideration is that surgical clips [13], metal debris [14], calcified lymph nodes, and so forth will show low signal intensity in PDIP-SOS images and potentially be confused with vascular calcifications that also appear dark. The easiest way to distinguish them from vascular calcifications is by showing their exact location with respect to the vessel wall, which is easily accomplished on fused images.

In no cases did fusion of QISS and PDIP-SOS images cause a significant loss of diagnostic information, e.g. by missing a significant arterial stenosis or large calcifications that might impact the choice of percutaneous access site. Moreover, there were no false positive cases of significant vascular calcifications or apparent arterial stenosis where none existed. In two cases, the degree of stenosis was classified as moderate by CTA but mild by fused MRA. Both cases demonstrated severe calcification at the site of the stenosis, so that CTA might have overestimated the degree of stenosis due to blooming artifact.

Our study focused on the ilio-femoral junction because of the importance of this region in percutaneous access. We anticipate that image fusion of MR angiographic and calcification-sensitive sequences could be similarly performed for other regions of the peripheral vascular system as well as in other vascular territories like the extracranial carotid bifurcation, although this remains to be studied. One limitation of the current approach for image fusion is the need to manually select landmarks prior to image registration. However, it should be possible to fully automate the image fusion process with further software development. Another potential concern is vessel size. While the fusion technique worked well in relatively large ilio-femoral vessels, it may be more challenging in smaller vessels such as the tibial or popliteal arteries where slight residual misregistration between the MRA and

PDIP-SOS data sets could cause artifacts in the fused images. Finally, any conclusions must be tempered by the small sample size. Further study in a larger cohort is warranted to better evaluate the accuracy of the fusion technique and to determine its utility over a range of vascular territories.

In conclusion, we found that the fusion of QISS non-contrast MRA and PDIP-SOS images enabled simultaneous evaluation of the arterial lumen and wall calcifications without loss of significant diagnostic information, potentially allowing for more complete and accurate MR vascular evaluation than would otherwise be possible. The proposed methodology may further enhance the utility and ease of use of magnetic resonance as an alternative to CTA in planning for percutaneous endovascular procedures.

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References

1. Met R, Bipat S, Legemate DA, Reekers JA, Koelemay MJ. Diagnostic performance of computed tomography angiography in peripheral arterial disease: a systematic review and meta-analysis. *JAMA* 2009;301:415–424 [PubMed: 19176443]
2. Menke J, Larsen J. Meta-analysis: Accuracy of contrast-enhanced magnetic resonance angiography for assessing steno-occlusions in peripheral arterial disease. *Ann Intern Med* 2010;153:325–334 [PubMed: 20820041]
3. Tranche-Iparraguirre S, Marin-Iranzo R, Fernandez-de Sanmamed R, Riesgo-Garcia A, Hevia-Rodriguez E, Garcia-Casas JB. Peripheral arterial disease and kidney failure: a frequent association. *Nefrologia* 2012;32:313–320 [PubMed: 22508143]
4. Miyazaki M, Lee VS. Nonenhanced MR angiography. *Radiology* 2008;248:20–43 [PubMed: 18566168]
5. Manunga JM, Gloviczki P, Oderich GS et al. Femoral artery calcification as a determinant of success for percutaneous access for endovascular abdominal aortic aneurysm repair. *J Vasc Surg* 2013;58:1208–1212 [PubMed: 23830310]
6. Niskanen L, Siitonen O, Suhonen M, Uusitupa MI. Medial artery calcification predicts cardiovascular mortality in patients with NIDDM. *Diabetes Care* 1994;17:1252–1256 [PubMed: 7821163]
7. Guzman RJ, Brinkley DM, Schumacher PM, Donahue RM, Beavers H, Qin X. Tibial artery calcification as a marker of amputation risk in patients with peripheral arterial disease. *J Am Coll Cardiol* 2008;51:1967–1974 [PubMed: 18482666]
8. Ouwendijk R, Kock MC, van Dijk LC, van Sambeek MR, Stijnen T, Hunink MG. Vessel wall calcifications at multi-detector row CT angiography in patients with peripheral arterial disease: effect on clinical utility and clinical predictors. *Radiology* 2006;241:603–608 [PubMed: 16966479]
9. Ferreira Botelho MP, Koktzoglou I, Collins JD et al. MR imaging of iliofemoral peripheral vascular calcifications using proton density-weighted, in-phase three-dimensional stack-of-stars gradient echo. *Magn Reson Med* 2017;77:2146–2152 [PubMed: 27297954]
10. Edelman RR, Sheehan JJ, Dunkle E, Schindler N, Carr J, Koktzoglou I. Quiescent-interval single-shot unenhanced magnetic resonance angiography of peripheral vascular disease: Technical considerations and clinical feasibility. *Magn Reson Med* 2010;63:951–958 [PubMed: 20373396]
11. Tang W, Hu J, Zhang H, Wu P, He H. Kappa coefficient: a popular measure of rater agreement. *Shanghai Arch Psychiatry* 2015;27:62–67 [PubMed: 25852260]
12. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med (Zagreb)* 2012;22:276–282 [PubMed: 23092060]

13. Hargreaves BA, Worters PW, Pauly KB, Pauly JM, Koch KM, Gold GE. Metal-induced artifacts in MRI. *AJR Am J Roentgenol* 2011;197:547–555 [PubMed: 21862795]
14. Makki D, Naikoti K, Murali SR. Magnetic resonance imaging signal artefacts from invisible metal debris following surgery to the elbow. *Shoulder Elbow* 2018;10:133–135 [PubMed: 29560040]

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Figure 1.

67-year-old male with peripheral arterial disease. (a) Axial QISS image shows bright intraluminal blood (arrow) in a moderately stenosed right common femoral artery, but the calcification is difficult to distinguish from dark background tissue. (b) Axial reformat from coronal PDIP-SOS clearly delineates the dark calcification (arrow), but with poor contrast between intraluminal blood and background tissue. (c) The resultant axial fused QISS and PDIP-SOS image simultaneously delineates bright intraluminal flowing blood (short arrow) and dark calcification (long arrow). There is excellent correlation between fused MRI and CTA (d).

Figure 2.

Top row: 71-year-old female with moderate vascular calcifications. (a) Axial fused MRI delineates bright intraluminal blood and dark calcification (arrow) in the left common femoral arterial wall with excellent correspondence to CTA (b). Bottom row: 66-year-old male with severe vascular calcifications. (c) Sagittal reformat of fused MRI shows bright intraluminal blood (short arrow) and dark calcifications (long arrows) with good correspondence to CTA (d). The calcifications appear slightly thicker on the CTA, likely due to blooming artifact.

Table 1.

Parameters of proton density-weighted, in-phase stack-of-stars (PDIP-SOS) and quiescent-inflow single-shot (QISS) sequences.

Parameters	PDIP-SOS	QISS
Slice orientation	Oblique coronal	Axial
Imaging Type	3D	2D
Cardiac Triggering	No	Yes
TR (ms)/TE (ms)/flip angle°	5.0/2.46/2.5	3.8/1.7/90
Slices	128	120
Slice thickness (mm)	0.5	3.0
In-plane resolution (mm)	1.0 × 1.0	1.0 × 1.0
Receiver bandwidth	750 Hz/pixel	960 Hz/pixel
Radial Views	600–660	--
Field of view (mm)	416 × 416	400 × 400
Matrix	416 × 416	400 × 260
Acquisition Time	7–8 min	7–8 min

Table 2.

Contingency table for stenosis on a vessel segment basis. Values are counts.

		CTA			Total
		Normal/Mild (0–49%)	Moderate (50–74%)	Severe (75%)	
Fusion MRI (QISS & PDIP-SOS)	Normal/Mild (0–49%)	21	2	0	23
	Moderate (50–74%)	0	3	0	3
	Severe (75%)	0	0	2	2
	Total	21	5	2	28