Simultaneous acquisition of spatially-registered gray- and black-blood images of peripheral arteries with 3D double-echo steady-state (DESS) at 3T

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Introduction: MRA is a luminal imaging technique that generates angiograms noninvasively. However, the method is unable provide information on arterial wall remodeling or accurate estimation of stenosis severity and detect calcification. Computed tomographic angiography (CTA) is often preferred for speed and high isotropic resolution allowing reformation in any direction. However, diffuse calcification can confound diagnosis [3], in particular in smaller infrapopliteal arteries, which are a common site of peripheral arterial disease (PAD) in diabetics [1,2]. Above limitations can be addressed with spatially-registered gray and black blood images. In this work we present a simple approach to achieving dual contrast with a 3D double-echo steady-state (DESS) pulse sequence for visualizing vessel wall and identifying calcification in patients with PAD.

Methods: Three-dimensional double-echo steady-state (DESS) [4], which collects SSFP-FID and SSFP-Echo is shown in **Fig 1**. The main contribution to the FID signal is the newly tipped transverse magnetization (no phase history) since the readout occurs before the application of the crusher gradient. In 2D imaging the FID signal is further increased by the flow enhancement; however, in a thick-slab 3D acquisition with short TR the spins of blood water will experience many RF pulses prior to exiting the slab. Thus, the number of pathways differing in phase will grow rapidly and will tend to destructively interfere, thereby attenuating the FID. The SSFP-Echo signal is weaker compared to the FID because the primary signal is the partially refocused FID from the previous pulse cycle. The refocused signal will be reduced further for the spins that move along the direction of unbalanced gradient (the effect is identical to having motion sensitizing or bipolar gradients separated by TR). The stimulated-echo pathways that also contribute to the final signal will have different phases resulting in destructive interference of the blood signal. ***In vivo* imaging**: 3D *in vivo* images of the femoropopliteal and infra-popliteal arteries of two young healthy volunteers (average age 29 years) were acquired with the 3D DESS pulse sequence of **Fig. 1** using the spine and two body matrix coils at 3T (Siemens TIM Trio). Further, gray and black blood images of femoropopliteal and infrapopliteal arteries were acquired on ten patients with PAD. Imaging parameters for femoropopliteal arteries: flip angle 8^{o}+8^{o}, TE_{FID}/TE_{Echo} /TR= 2.2/7.8/10.6 ms, bandwidth=744 Hz/voxel (FID), 223 Hz/voxel (Echo), FOV=352×192×360 mm^3, spatial resolution=0.78×0.78×3 mm^3, NEX=1, acquisition time (TA) = 5.2 mins. Smaller FOV and higher spatial resolution were used to image infrapopliteal arteries (FOV=288×128×360 mm^3, spatial resolution=0.64×0.64×3 mm^3, TA = 4.4 mins) but the remaining parameters were kept the same. Images were zero-padded to 0.39×0.39×1.5 mm^3 or 0.32×0.32×1.5 mm^3.

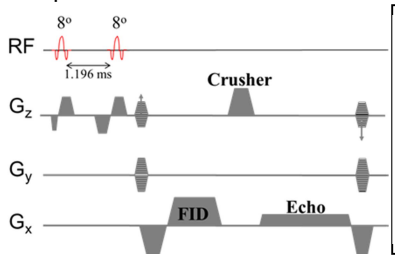

Fig 1 3D double-echo steady-state (DESS) pulse sequence. The 1-1 binomial pulse is used to attenuate the fat signal, and the crusher gradient (applied along the cranio-caudal direction after the FID readout) ensures separation between FID and Echo (2^{nd} readout) in k-space. FID is read out with higher bandwidth to minimize TR and increase muscle tissue SNR of Echo.

Results: 3D SSFP images of peripheral arteries are shown in Fig.1 for a healthy subject and Figs. 2 and 3 in two PAD patients.

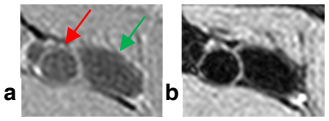

Fig 2 Magnificed view of femoral artery (red arrow) and vein(green arrow). **a**) SSFP-FID and **b**) SSFP-Echo clearly demonstrating distinct lumen contrast in the femoral artery, i.e. moderate signal in the lumen (**a**) versus full suppression of the blood signal (**b**).

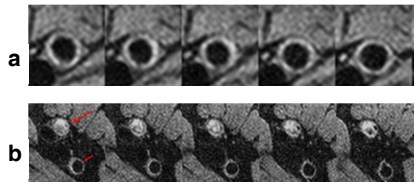

Fig 2 Visualization of wall-thickening of the right superficial femoral artery in a 67 yr old patient with **a**) normal ABI (1.07) in one leg but **b**) PAD (ABI=0.71) in the contralateral leg, where there is significant luminal stenosis in the superficial femoral artery (longer red arrow) while the deep femoral artery (shorter red arrow) is mostly patent.

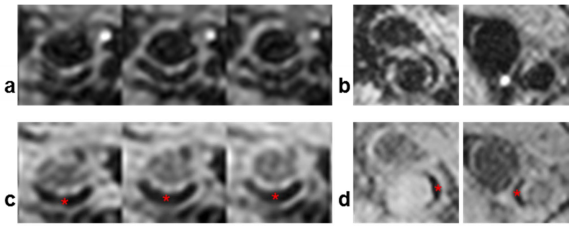

Fig 3 Identification of calcification appearing as signal void (red asterisk) on both (**a**, **b**) black and (**c**, **d**) grey blood images. **a**, **c**) and **b**, **d**) were acquired from a patient with ABI=0.71 (67 yrs old) and 0.82 (64 yrs old), respectively.

Conclusions: Pairing 3D DESS, a fast unbalanced SSFP pulse sequence, with non-contrast MRA has the potential to improve diagnosis of PAD since the dual-contrast of DESS allows assessment of the severity of stenosis, arterial wall remodeling and identification of calcification. Lastly, 3D DESS dual-contrast has the potential to resolve confounding diffuse calcification that can limit the usefulness of CTA in many patients with diabetes.

References: [1] ADA, Diabetes care 2003, [2] Strandness et al, Diabetes 1964, [3] Pomposelli F, J Vasc Surg 2010, [4] Bruder et al, MRM 1988.

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