Fast Three-Dimensional Black-Blood MR Imaging for Carotid Artery Intra-plaque Haemorrhage Using DANTE-Prepared FLASH (3D-DASH)

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Background: DANTE (Delays Alternating with Nutation for Tailored Excitation) pulse trains are a rapid series of low flip angle RF pulses interspersed with gradients. We have previously demonstrated that when DANTE pulse trains are used as a preparation module prior to imaging readout, the longitudinal magnetization of flowing spins is substantially attenuated, whereas the longitudinal magnetization of static tissue/fluid is mostly preserved [1]. In this study we introduce a new DANTE-prepared 3D FLASH T_1 weighted (T1w) sequence (denoted '3D-DASH') that is able to generate 0.6 mm isotropic resolution carotid artery intra-plaque haemorrhage black blood images with an imaging speed better than 2 sec/slice. Imaging efficiency comparisons were also made between the current best 3D black blood (BB) technique, MSDE prepared FLASH (3D-MERGE)[2] and the new 3D-DASH technique.

Materials and Methods: Subjects: 6 healthy volunteers (males, 24 to 35 years) underwent (i) DIR, (ii) 3D-DASH and (iii) comparison 3D-MERGE imaging. Additionally, 2 symptomatic patients with carotid artery disease underwent carotid vessel wall imaging (the presence of intra-plaque haemorrhage was subsequently confirmed from histology, not shown). Written informed consent was obtained from all subjects. All scans were acquired using a 3T Siemens Verio scanner. A pair of dual-channel surface coils (Machnet, Eelde, Netherlands) was used for the carotid scans. No breath holding was used. Cardiac gating was used for comparison DIR-prepared black blood scans. *Protocol*: axial imaging acquisition, identical 3D FLASH readout sequences for 3D-DASH and 3D-MERGE, FOV=150 × 150 x 60mm, matrix size 256 × 252 x 128, interpolated to 512 × 512, Number of averages = 2, iPat = 2, FLASH flip angle α = 10°, slice resolution = 63%, phase and slice partial FT = 6/8, Fat suppression = water excitation-fast, $TR_{internal}$ = 10 ms, BW = 130 Hz/pixel, resolution=0.6mm isotropic. Parameters for the DANTE module: flip angle (FA) α = 15°; Number of DANTE pulses N_p=150; time duration between DANTE pulses, t_D=1 ms; $G_{x,y,z}$=20 mT/m; gradient duration≈1 ms. Effective CNR was calculated for 3D-DASH and 3D-MERGE, accounting for scan durations.

Results:

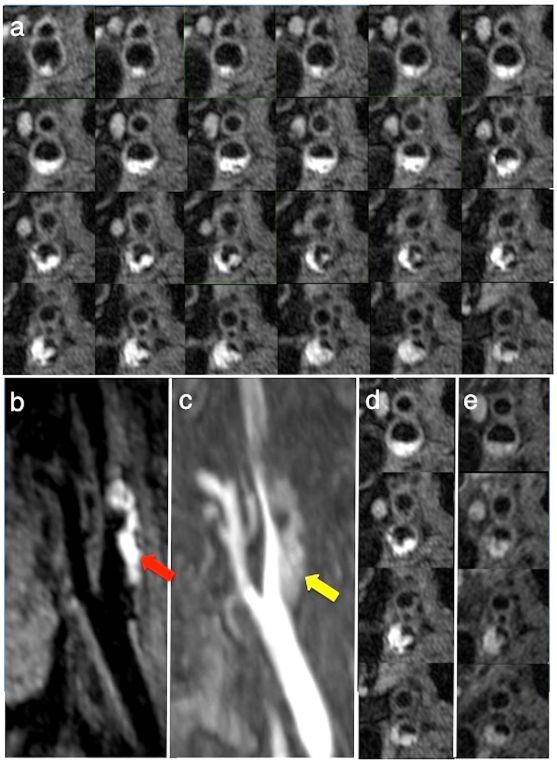

Fig. 1. T1w 3D-DASH images obtained from a patient with intra-plaque haemorrhage. a) 24 contiguous-slice whole plaque coverage from 3D-DASH images with isotropic 0.6 mm resolution. b) 3D-MPR sagittal view of the left carotid arteries reconstructed from the full 128-slice 3D-DASH dataset. c) 3D-MPR sagittal view reconstructed from the 3D-TOF data for comparison. d) and e) Axial view slices of 3D-DASH and DIR-prepared 2D-TSE images taken from the same slice positions for direct comparison.

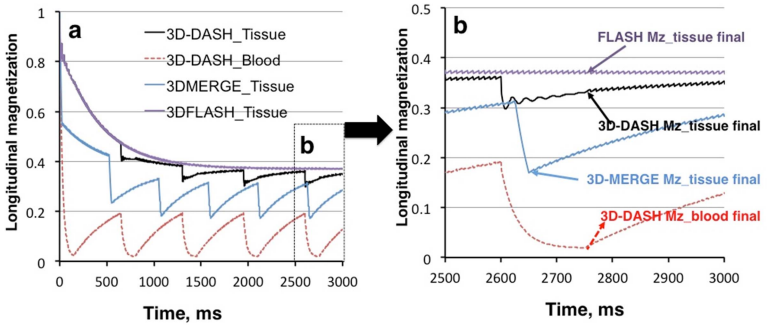

Fig. 2. a) Bloch Simulations showing longitudinal relaxation effects of T1w 3D-FLASH, 3D-DASH and 3D-MERGE protocols (including relaxation effects associated with the FLASH readout). b) Magnified block from (a) showing that 3D-DASH may have significant signal gain improvement compared with 3D-MERGE.

Examples of the T1w image quality for the 3D-DASH sequence with 0.6 mm isotropic resolution versus the gold standard single-slice DIR (double inversion recovery)-prepared 2D-TSE sequence with slice thickness 2 mm are shown in Fig. 1. The 3D-DASH scan acquisition time was 198 seconds, with >6 cm coverage (128 slices). The hyper-intense signal on the T1w images indicates the presence of fresh intra-plaque haemorrhage (IPH) confirmed by histological examination. Compared with the current best 3D black blood (BB) technique MSDE prepared FLASH (3D-MERGE), through Bloch simulation Fig. 2 and in-vivo image Fig 3, 3D-DASH allows 75%-100% improvement in contrast-to-noise efficiency, CNR_{eff}.

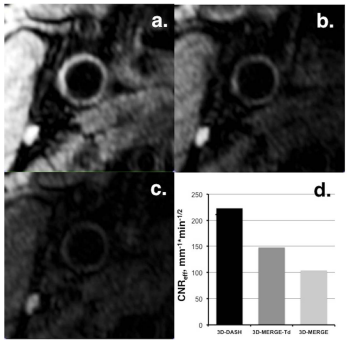

Fig. 3. Comparisons of effective CNR (same greyscale) from 3D-DASH, 3D-MERGE-Td (with post acquisition delay) and 3D-MERGE (without post acquisition delay) obtained from a representative healthy subject. a) Axial slice from 3D-DASH. b) Axial slice from 3D-MERGE-Td. c) Axial slice from 3D-MERGE. Note, the acquisition times of 3D-DASH and 3D-MERGE-Td are identical, whereas the acquisition time of 3D-MERGE is 1 minute shorter.

Conclusions 3D-DASH is a promising new sequence for fast black-blood T_1 weighted imaging of carotid artery intra-plaque haemorrhage.

Acknowledgements and References We thank the NIHR Oxford Biomedical Research Centre, British Heart Foundation, and Dunhill Medical Trust for grant funding.

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