Carotid Plaque Assessment using Fast 3D Isotropic-Resolution Black-Blood MRI

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Introduction: High-resolution MRI of carotid atherosclerotic plaque allows identification of plaque morphologic and compositional properties associated with the risk of stroke [1]. Most plaque MRI protocols typically use 2D black-blood imaging sequences, which limit information to be gained in the slice select direction. 3D sequences which may potentially overcome this problem, have a number of limitations such as prohibitively long scan time, inadequate flow suppression, and non-isotropic voxel size due to SNR restrictions. Motion-sensitized driven equilibrium (MSDE) preparation has been recently suggested to improve quality of 3D black-blood imaging [2]. However, a better time-efficiency is still needed for this approach. Another practical aspect of MSDE-based sequences, which has not been studied, is their capability to provide a desired contrast for identification of plaque composition.

Table 1: Imaging Parameters

	3D BB	TOF	T1w	T2w
Mode	3D	3D	2D	2D
Acquisition plane	Coronal	Axial	Axial	Axial
Resolution, mm^2	0.7	0.55	0.55	0.55
FOV, mm^2	250×160	140x140	140x140	140x140
Slice thickness , mm	0.7	2	2	2
# of slices	100	48	16	16
TR/TE, ms	10/4.8	20/5	800/10	4000/50
Flip angle, °	6	20	90	90
Turbo factor	90	-	10	12
BW, Hz/pixel	134.3	289.7	170.7	201.1
NSA	1	1	1	1
Scan time, min:s	2:03	1:58	5:45	2.48

Table 2: Criteria for identification of plaque components

	CA	IPH	LC
On 3D BB	No signal	Hyperintense	Hypointense
On Reference sequence	No signal on TOF	Hyperintense on TOF and T1	Hypointense on T2w, except IPH

Aims: 1) To develop a new sequence capable of obtaining high-quality 3D black-blood carotid MRI with isotropic spatial resolution within a clinically acceptable scan time; 2) To compare the new 3D sequence to existing MR contrast weightings in its ability to visualize the three major plaque components: calcification (CA), intra-plaque hemorrhage (IPH) and lipid core (LC).

Materials and Methods: 3D Black-blood Sequence: A new 3D sequence (3D BB) was implemented with MSDE preparation [2] and spoiled segmented FLASH (or turbo field echo, T1-TFE) readout with centric phase encoding. Sequence parameters were adjusted to obtain isotropic resolution of 0.7mm^3 (zero-interpolated to 0.35mm^3) with a scan time of 2 min. Images were acquired in the coronal plane such that the entire carotid artery covered by the coil was imaged. **Imaging:** 15 patients with 16-79% stenosis by duplex ultrasound, were recruited and scanned according to institutional review board guidelines. Images were acquired on a Philips Acheiva 3T scanner with a bilateral four-channel phased array carotid coil. The protocol included 3D BB, 3D TOF, 2D T1w Quadruple Inversion Recovery [3] and 2D T2w Multislice DIR [4] sequences with parameters listed in Table 1. **Image analysis:** Bilateral carotid bifurcations (30 arteries) were reviewed for presence or absence of CA, IPH and LC. Plaque components were identified using the published [1] criteria summarized in Table 2. 3D BB images were analyzed separately from the other three weightings. Interactive multi-planar reformatting of the isotropic dataset was used to visualize plaques on 3D BB images. **Statistical analysis:** Sensitivity, Specificity and Cohen's Kappa were used to determine agreement between 3D BB and the standard carotid imaging sequences.

Results: 3D BB identified all CA with few false positives (Table 3). It was sensitive for IPH with high specificity. 3D BB was less sensitive in detecting LC but highly specific. There was good agreement between 3D BB and other weightings for detection of all three components ($p<0.0001$). Representative cases are shown in figures 1-3.

Discussion: 3D MSDE-TFE sequence is characterized by complex contrast properties, where several factors simultaneously affect the behavior of magnetization. Particularly, low-angle FLASH-like readout in the non-steady-state regime mostly introduces proton-density contrast, while a variable degree of T1 weighting can be added depending on the TFE shot duration and phase encoding order. MSDE preparation can considerably modify image contrast by both its T2 and diffusion effects [5]. This study indicates that a combination of these contrast mechanisms can be helpful for developing an all-in-one solution for fast BB carotid imaging, simultaneously providing angiographic lumen information and identification of high-risk plaque features.

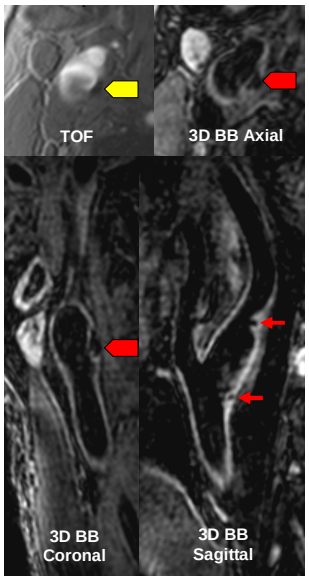

Fig 1, Calcification: Dark signal corresponding to calcification on TOF (yellow arrow) is also seen on axial and coronal reformats of 3D BB (red arrows). Sagittal reformat shows other calcificates (thin arrows).

Conclusion: The newly developed fast isotropic 3D black-blood sequence was validated on 15 patients with atherosclerotic disease and produced images of diagnostic quality with extended coverage. Major determinants of plaque vulnerability such as CA, IPH and LC can be reliably identified using the new sequence. Isotropic voxels allowed interactive reformatting in arbitrary planes providing a more thorough visualization of plaque components. The 3D BB sequence promises to be a valuable tool for simultaneous plaque burden measurement and tissue characterization.

References: [1] Saam, Radiology 2007; 244:64-77, [2] Koktzoglou, Radiology 2007; 243:220-8, [3] Yarnykh, MRM 2002; 48:899-905, [4] Yarnykh, JMRI 2003; 17:478-83, [5] Wang, MRM 2007; 58:973-81

Table 3: Plaque components identified by 3D BB

		Calcification	Hemorrhage	Lipid core
	Sensitivity	100%	86%	71%
	Specificity	71%	91%	96%
	Kappa	0.79	0.73	0.71

Contingency Table

		TOF		TOF/T1		T2w	
		Yes	No	Yes	No	Yes	No
3D BB	Yes	23	2	6	2	5	1
	No	0	5	1	21	2	22

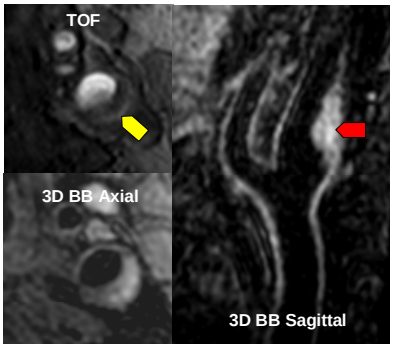

Fig 2, Hemorrhage: Bright signal on TOF (yellow arrow) corresponds to hyperintensity on reformatted axial and sagittal 3D BB.

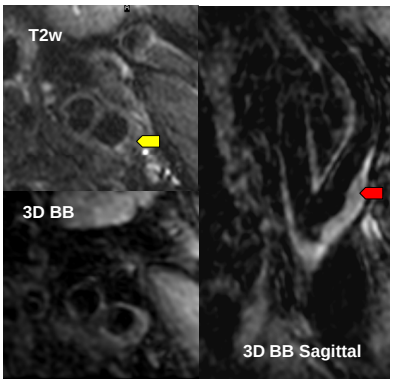

Fig 3, Lipid core: Hypointense lipid core seen on axial T2w (yellow arrow) is also visualized on axial reformat of 3D BB. Its extent can be clearly visualized on sagittal reformat (red arrow).